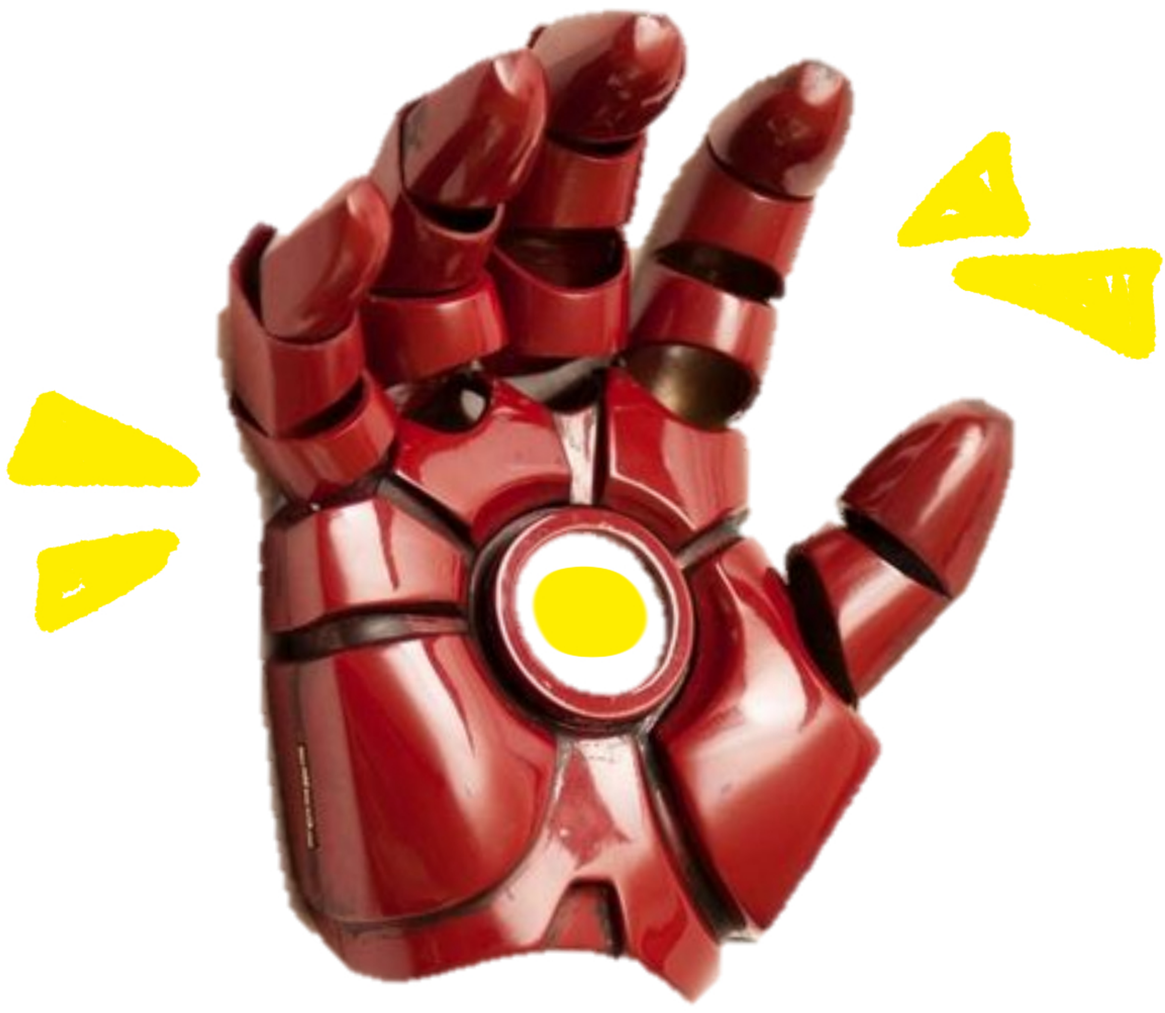
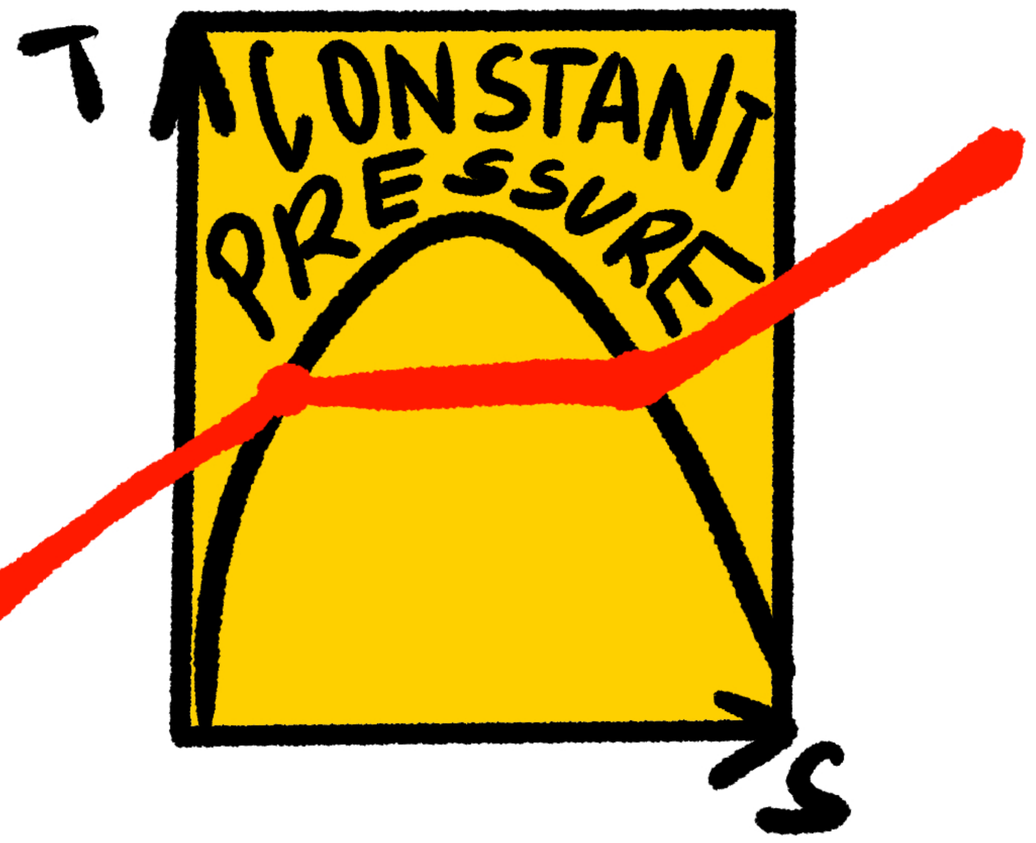
POWER PLANT ENGINEERING



LABRA, EAN
2020



HEY THERE! IF YOU'RE READING THIS, YOU'RE PROBABLY STUDYING. PROBABLY!! PRESSURE WILL ALWAYS BE THERE – EMBRACE IT. IN A RANKINE CYCLE, WORK HAPPENS AFTER CONSTANT PRESSURE. PADAYON LANG!

CONSTANT PRESSURE = CONSTANT HUSTLE!

– LABRA (PANDEMIC, 2020)

CONVERSIONS AND CONSTANTS

NUMERICAL PREFIXES

PREFIX	SYMBOL	EXPONENT
EXA	E	10^{18}
PETA	P	10^{15}
TERA	T	10^{12}
GIGA	G	10^{9}
MEGA	M	10^{6}
KILO	k	10^{3}
HECTO	h	10^{2}
DECA	da	10
DECI	d	10^{-1}
CENTI	c	10^{-2}
MILLI	m	10^{-3}
MICRO	M	10^{-6}
NANO	n	10^{-9}
PICO	p	10^{-12}
FEMTO	f	10^{-15}
ATTO	a	10^{-18}

VOLUME

1 QUART = 2 PINTS
1 US. GALLON = 3.785 LITERS
= 4 QUARTS
1 BRIT. GALLON = 277.42 in^3
1 ft^3 = 7.48 US. GALLONS
1 BARREL (bbl) = 42 GALLONS
1 GANTA = 3 LITERS
= 8 CHUPAS
1 CAVAN = 25 GANTAS

MASS

1 TONNE = 1 METRIC TON
= 1000 kg
1 SHORT TON = 2000 lbsm
1 LONG TON = 2240 lbsm
1 kg = 2.21 lbs
1 lbs = 16 oz.
1 SLUG = 32.2 lbsm

DENSITY / CONCENTRATION

1 kg/L = 62.4 lb/ft^3
1 ppm = 1 mg/L
= 1 mg/kg

FORCE

1 N = 100,000 DYNES
1 kgf = 9.81 N
1 lbf = 4.448 N

DISTANCE, SPEED, ACCEL.

1 STATUTE MILE = 5280 ft.
1 NAUTICAL MILE = 6080 ft.
1 LEAGUE = 3 NAUTICAL MILES
1 YARD = 3 FEET
1 METER = 3.281 FT.
1 FOOT = 12 INCHES
1 INCH = 2.54 cm.
1 ROD = 5.5 YARDS
1 FURLONG = 220 YARDS
1 CABLE LENGTH = 720 FT.
1 FATHOM = 6 ft.
1 CHAIN = 66 ft.
1 FURLONG = 660 ft.
1 SPAN = 9 INCHES

1 LIGHT YEAR = 9.46×10^{12} m
1 KNOT = 1 NAUT. MILE/hr.
1 m/s = 3.6 kph
9.81 m/s^2 = 32.2 ft/s^2

AREA

1 ACRE = 1 FURLONG × 1 CHAIN
= 660 ft × 66 ft
1 ARE = 100 m^2
1 HECTARE = 10,000 m^2

ANGLES

1 REV = 2π RAD = 360°
= 400 GRAD = 400 GONS
= 6400 MILS

PRESSURE

1 atm = 101.325 kPa
= 14.7 psi
= 760 mmHg
= 29.92 inHg
= 1.032 kg/cm^2
= 760 torr
1 bar = 100 kPa

ENERGY

1 BTU = 778 ft-lb
= 252 cal
= 1055 J
1 kcal = 4.187 kJ
1 JOULE = 10^7 erg
1 erg = 1 DYNE − cm
1 CENTIGRADE HEAT UNIT (CHU) = 1.8 BTU
1 ev = 1.602×10^{-19} J

POWER

1 hp = 0.746 kW
= 550 lb-ft/s
= 33000 lb ft/min
= 2545 BTU/hr
= 42.4 BTU/min
= 1.014 Mhp
1 BOILER hp = 35,322 kJ/hr
1 TOR = 3.516 kW
= 12000 BTU/hr
1 METRIC hp (Mhp) = 0.736 kW

TEMPERATURE

$°F = 1.8C + 32$
$°C = \frac{(F-32)}{1.8}$
$R = °F + 460$
$K = °C + 273$

$\Delta T_F = 1.8\Delta T_C$
$\Delta T_K = \Delta T_C$
$\Delta T_R = \Delta T_F$
$1°Re = \frac{4}{5}°C$
$1°Re = 20°L$

VISCOSITY

ABSOLUTE	KINEMATIC
1 REYN = 1 $\frac{lb\text{-}sec}{in^2}$	1 STOKE = 1 $\frac{cm^2}{s}$

1 POISE = 1 $\frac{DYNE\text{-}s}{cm^2}$
= 0.1 Pa-s

CONSTANTS

GAS LAWS

$\bar{R} = 8.3143 \frac{J}{mol \cdot K}$
$= 1545 \frac{lbf\text{-}ft}{lbm \cdot mol \cdot R}$
$= 0.0821 \frac{L\text{-}atm}{mol\text{-}K}$

GENERAL

$g = 9.81\ m/s^2$
$N_A = 6.022 \times 10^{23}\ mol^{-1}$
$\sigma = 5.67 \times 10^{-8} \frac{W}{m^2 K^4}$
$C = 3 \times 10^8 \frac{m}{s}$
SOLAR CONSTANT = $1353 \frac{W}{m^2}$
PLANCK'S C. (h) = 6.626×10^{-34} J·S
GRAVITATIONAL C. (G) = $6.664 \times 10^{11} \frac{Nm^2}{kg}$
RADIUS OF EARTH = 6.38×10^6 m
VEL. TO ESCAPE EARTH = 11.2 km/s
HUMAN HEAT = 225 BTU/hr

PROPERTIES OF AIR / GASES

$C_p = 1 \frac{kJ}{kgK} = 0.24 \frac{BTU}{lbR}$
$C_v = 0.7186 \frac{kJ}{kgK} = 0.1714 \frac{BTU}{lbR}$
$R = 0.287 \frac{kJ}{kgK} = 53.34 \frac{lb\text{-}ft}{lb\ °R}$
k = 1.4
= 1.3 (HOT)
$\rho = 1.2\ kg/m^3$
$= 0.075 \frac{lb}{ft^3}$

MOL. WTS.
H = 1
He = 4
C = 12
N = 14
O = 16
S = 32
AIR = 28.97

K OF GASES

He, NOBLE GASES	1.667
CARBON DIOXIDE CO_2	1.287
NITROGEN, N_2	1.399

PROPERTIES OF H_2O / LIQUIDS

$C_{p_W} = 4.187 \frac{kJ}{kg\,K} = 1.0 \frac{BTU}{lbR}$
$C_{p\,ice} = 2.093 \frac{kJ}{kg\,K} = 0.5 \frac{BTU}{lb\,R}$

LATENT HEATS:

ICE: L_f = 334 kJ/kg = 144 BTU/lb
WATER: L_v = 2257 kJ/kg = 970 BTU/lb

SURFACE TENSION:
@ 0°C = 0.076 N/m
@ 100°C = 0.059 N/m

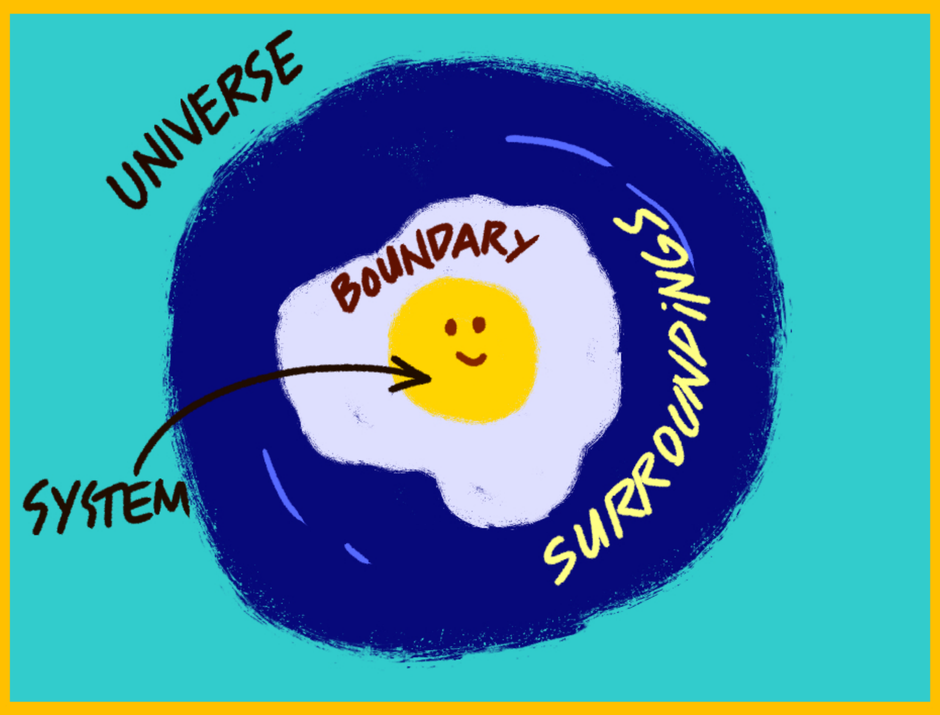
SG:
$SG_{Hg} = 13.6$
$SG_{sea} = 1.03$

STEEL

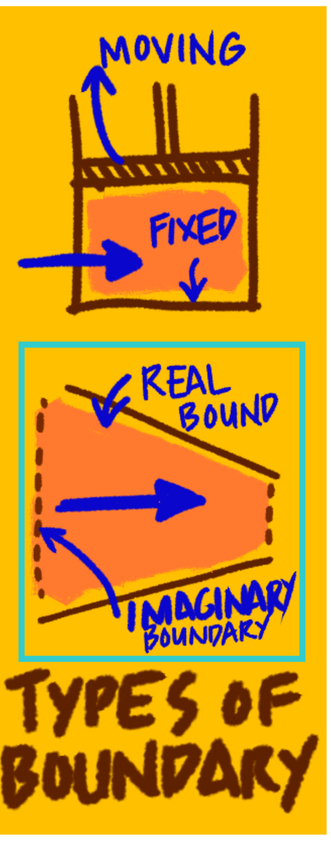
$E = 30 \times 10^6$ psi = 210 GPa
$G = 12 \times 10^6$ psi = 83 GPa
$\alpha = 11.7 \times 10^{-6}/°C = 6.5 \times 10^{-6}/°F$
$\rho = 7850 \frac{kg}{m^3} = 490 \frac{lb}{ft^3}$

THERMODYNAMICS

THE BRANCH OF PHYSICAL SCIENCE THAT DEALS WITH THE **RELATIONS BETWEEN HEAT AND OTHER FORMS OF ENERGY.**

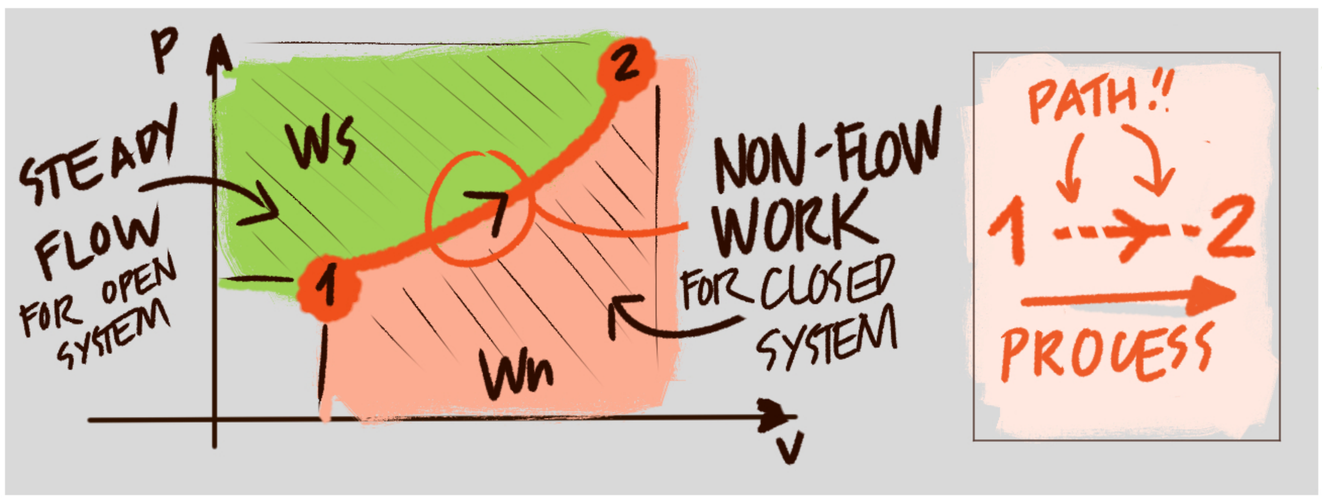


SYSTEM	REFER TO ANY PART OF THE UNIVERSE BEING STUDIED
SURROUNDINGS	THE MASS OF REGION OUTSIDE THE SYSTEM
BOUNDARY	THE REAL OR IMAGINARY SURFACE THAT SEPARATES THE SYSTEM FROM ITS SURROUNDINGS
UNIVERSE	SYSTEM + SURROUNDINGS



TYPES OF BOUNDARY

TYPES OF SYSTEM	MATTER	ENERGY	WORK/PROCESS
CLOSED SYSTEM	NO	YES	*NON-FLOW/CONTROL MASS*
OPEN SYSTEM	YES	YES	*STEADY FLOW/CONTROL VOLUME*
ISOLATED SYSTEM	NO	NO	



FOR STEADY FLOW:

$W_S = -\int V dP$

$W_S = V(P_1 - P_2)$

FOR NON-FLOW:

$W_N = \int P dV$

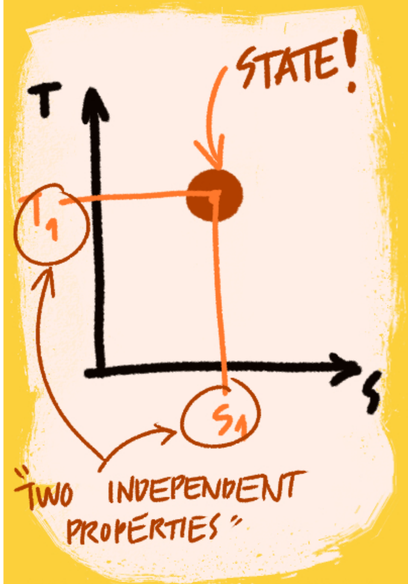
$W_N = P(V_2 - V_1)$

PROCESS: ANY CHANGE THAT A SYSTEM UNDERGOES *FROM ONE EQUILIBRIUM STATE TO ANOTHER.*

PATH: THE *SERIES OF STATES* THROUGH WHICH A SYSTEM PASSES DURING A PROCESS.

QUASISTATIC OR QUASI-EQUILIBRIUM PROCESS: WHEN A PROCESS PROCEEDS IN SUCH A MANNER THAT THE SYSTEM REMAINS *INFINITESIMALLY CLOSE TO AN EQUILIBRIUM* STATE AT ALL TIMES.

STATE POSTULATE



THE **STATE** OF A SIMPLE COMPRESSIBLE SYSTEM IS COMPLETELY SPECIFIED BY *TWO INDEPENDENT, INTENSIVE PROPERTIES.*

THERMODYNAMIC PROPERTIES

1. MASS
2. PRESSURE

$P_{abs} = P_{gage} + P_{atm}$

$P_{abs} = P_{gage} + P_{baro}$

CONVERSIONS:

1 atm =
- = 101.325 kPa = 1.032 kg/cm²
- = 14.7 psi = 760 torr
- = 29.92 in.Hg = 1.013 bar
- = 760 mmHg = 10.33 m H_2O
- = 34 ft H_2O

3. TEMPERATURE

$F = 1.8C + 32$

$C = (F - 32)/1.8$

$R = F + 460$

$K = C + 273$

CONVERSIONS:

$\Delta T_F = 1.8 \Delta T_C$

$\Delta T_K = \Delta T_C$

$\Delta T_R = \Delta T_F$

$1°Re = \frac{4}{5}°C$

$1°Re = 20°L$

INTENSIVE PROPERTIES	EXTENSIVE PROPERTIES
• DENSITY	• TOTAL VOLUME
• SPECIFIC GRAVITY	• ENERGY
• TEMPERATURE	• TOTAL MASS
• PRESSURE	• TOTAL MOMENTUM

4. SPECIFIC VOLUME

- VOLUME PER UNIT MASS

$v = \frac{V}{m} \qquad v = \frac{1}{\rho}$

SPECIFIC GRAVITY / RELATIVE DENSITY

$SG = \frac{\rho_{fluid}}{\rho_{std.}} = \frac{\gamma_{fluid}}{\gamma_{std.}}$

WATER @ STP

$\gamma_w = 9.81 \frac{kN}{m^3}$ | $\rho_w = 1000 \frac{kg}{m^3}$

$\gamma_w = 62.4 \frac{lbf}{ft^3}$ | $\rho_w = 1 \frac{kg}{L}$

$\rho_w = 62.4 \frac{lbm}{ft^3}$

THERMODYNAMIC PROPERTIES (CONTINUATION)

5. INTERNAL ENERGY

- THE **SUM OF ALL THE MICROSCOPIC FORMS OF ENERGY** IS CALLED THE INTERNAL ENERGY OF A SYSTEM AND IS DENOTED BY U.

6. ENTHALPY

- WHICH IS THE SUM OF THE INTERNAL ENERGY OF THE SYSTEM PLUS THE PRODUCT OF THE PRESSURE OF THE GAS IN THE SYSTEM TIMES THE VOLUME OF THE SYSTEM.

$$H_{sys} = U_{sys} + W_f \rightarrow \text{WORK!}$$
$$= U_{sys} + PV$$
$$h = u = Pv \rightarrow \text{FOR SPECIFIC ENTHALPY } \left(\frac{kJ}{kg}\right)$$

7. ENTROPY

- ENTROPY IS THE LOSS OF ENERGY AVAILABLE TO DO WORK

$$S = \sum \Delta S$$
$$\Delta S = \int dS = \int \frac{dQ_{rev}}{T}$$

WHERE: Q = HEAT, T = TEMP.

8. SPECIFIC HEAT

- IT IS THE AMOUNT OF ENERGY THAT MUST BE ADDED, IN THE FORM OF HEAT, TO ONE UNIT OF MASS OF THE SUBSTANCE IN ORDER TO CAUSE AN INCREASE OF ONE UNIT IN ITS TEMPERATURE.

$$c = \frac{Q}{m(\Delta T)}$$

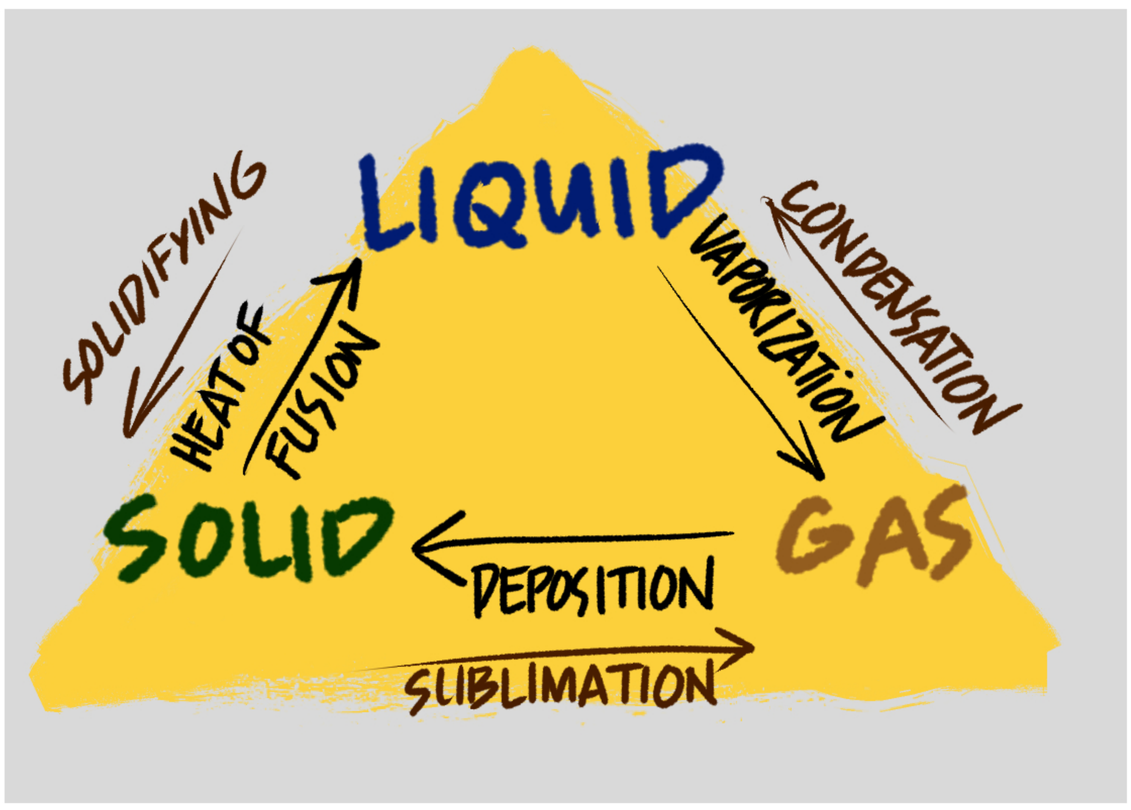
Q = HEAT, m = MASS, ΔT = CHANGE IN TEMP.

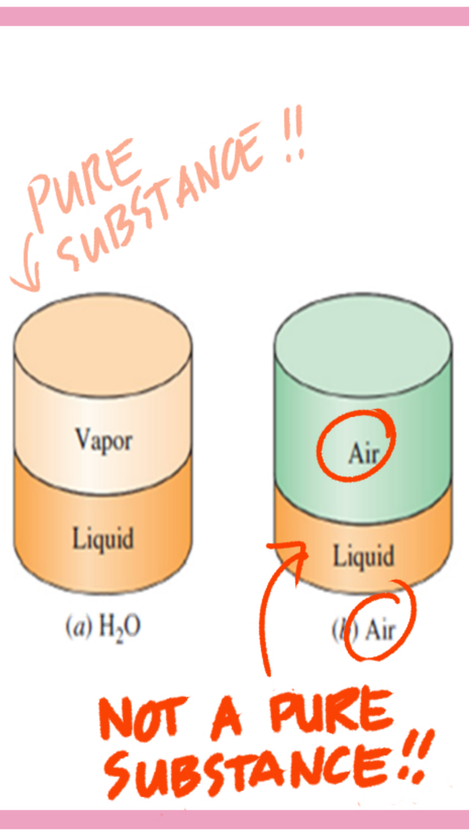
FOR GASES:
$Q = mc_v(\Delta T) \rightarrow$ (CONSTANT-VOLUME PROCESS)
$Q = mc_p(\Delta T) \rightarrow$ (CONSTANT-PRESSURE PROCESS)

PURE SUBSTANCE

- A WORKING SUBSTANCE WHOSE CHEMICAL COMPOSITION REMAINS THE SAME EVEN IF THERE IS A CHANGE IN PHASE
- A SUBSTANCE THAT HAS A FIXED CHEMICAL COMPOSITION THROUGHOUT

WATER, NITROGEN, HELIUM, AND CARBON DIOXIDE, FOR EXAMPLE, ARE ALL PURE SUBSTANCES.





PURE SUBSTANCES

- AIR
- LIQUID WATER AND ICE
- GASEOUS WATER AND ICE

LIQUID AIR AND GASEOUS AIR - NOT A PURE SUBSTANCE – NO LONGER CHEMICALLY HOMOGENEOUS BECAUSE OF *DIFFERENT COMPONENTS OF AIR CONDENSING AT DIFFERENT TEMPERATURES*

COMPRESSED LIQUID VS. SUBCOOLED LIQUID ???

COMPRESSED LIQUID

- LIQUID WHOSE PRESSURE IS HIGHER THAN THE SATURATION PRESSURE AT THE GIVEN TEMPERATURE
- IF THE TEMPERATURE IS HELD CONSTANT AND THE PRESSURE IS INCREASED BEYOND THE SATURATION PRESSURE

SUBCOOLED LIQUID

- LIQUID WHOSE TEMPERATURE IS LOWER THAN THE SATURATION TEMPERATURE AT THE GIVEN PRESSURE

GENERAL GAS LAWS

IDEAL GAS

- A WORKING SUBSTANCE WHICH **REMAINS IN GASEOUS STATE** DURING ITS OPERATING CYCLE AND WHOSE EQUATION OF STATE IS:

$$PV = mRT$$
$$PV = n\bar{R}T$$

WHERE:
P = ABS. PRESSURE OF GAS
T = ABS. TEMPERATURE OF GAS
V = VOLUME OF GAS

m = MASS OF GAS
$m = n(MW)$
n = no. of MOLES, MW = MOLECULAR WEIGHT

R = IDEAL GAS CONST.
$\bar{R}$ = UNIVERSAL GAS CONST.

$$\bar{R} = 8.314 \frac{kJ}{kmol\text{-}K} = 1545 \frac{ft\text{-}lbf}{lbmol\text{-}R}$$

RELATIONS OF SPECIFIC HEATS OF AN IDEAL GAS

@ CONSTANT PRESSURE:

$$c_p = \frac{kR}{k-1} = \frac{dH}{mdT}$$

@ CONSTANT TEMPERATURE:

$$c_v = \frac{R}{k-1} = \frac{dU}{mdT}$$

$c_p - c_v = R$

SPECIFIC HEAT RATIO (k):

$$k = \frac{c_p}{c_v}$$

CONSTANTS OF WATER

$C_p = 4.187 \frac{kJ}{kgK}$

$= 1.0 \frac{BTU}{lbR}$

FOR ICE:

$C_{p\,ice} = 2.0\,3 \frac{kJ}{kgK}$

$= 0.5 \frac{BTU}{lbR}$

ENERGY CONVERSIONS:

1 BTU = 1.055 kJ
= 778 $lb_f \cdot ft$

1 erg = 1 dyne - cm
= 10^{-7} Joules

1 cal = 4.187 J

CONSTANTS OF AIR

$k = 1.4$ or 1.3 (HOT)

$C_p = 1 \frac{kJ}{kgK} = 0.24 \frac{BTU}{lbR}$

$C_v = 0.7186 \frac{kJ}{kgK} = 0.1714 \frac{BTU}{lbR}$

$R = 0.287 \frac{kJ}{kgK}$

$R = 53.34 \frac{BTU}{lbR}$

DENSITY of AIR

$\rho = 1.2 \frac{kg}{m^3}$

"SPECIFIC HEAT RATIO OF GASES"

	GAS	k
AHMN	ARGON (A)	1.666
AHMN	HELIUM (He)	1.666
AHMN	MERCURY (Hg)	1.666
AHMN	NEON (Ne)	1.666
	AIR	1.4
	HYDROGEN (H_2)	1.4
	CARBON MONOXIDE (CO)	1.399
	NITROGEN (N_2)	1.399
	OXYGEN (O_2)	1.395
	METHANE (CH_4)	1.321
	AMMONIA (NH_3)	1.304
	CARBON DIOXIDE (CO_2)	1.288

AVOGADRO'S CONST

$N_A = 6.022 \times 10^{23}\ mol^{-1}$

CONSTANTS!!

: LATENT HEATS :

ICE:

$L_f = 334 \frac{kJ}{kg} = 144 \frac{BTU}{lb} = 80 \frac{cal}{g}$

BOILING H_2O:

$L_v = 2257 \frac{kJ}{kg} = 970 \frac{BTU}{lb} = 540 \frac{cal}{g}$

GENERAL GAS EQUATIONS

GENERAL GAS LAWS	CONSTANT VARIABLE	EQUATION
CHARLES' LAW	PRESSURE	$\frac{V_1}{T_1} = \frac{V_2}{T_2}$
BOYLE'S LAW	TEMPERATURE	$P_1V_1 = P_2V_2$
GAY LUSSAC'S LAW	VOLUME	$\frac{P_1}{T_1} = \frac{P_2}{T_2}$
AVOGADRO'S LAW	PRESSURE, TEMPERATURE	$\frac{V_1}{n_1} = \frac{V_2}{n_2}$ $\frac{M_1}{M_2} = \frac{m_1}{m_2} = \frac{R_1}{R_2}$ (ONLY @ CONSTANT V,P,T)
COMBINED GAS LAW	NONE	$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$

MIXTURES INVOLVING IDEAL GASES:

- MASS OR GRAVIMETRIC ANALYSIS

$$m = \frac{m_a}{m_t} + \frac{m_b}{m_t} + \frac{m_c}{m_t} + \dots$$

- VOLUME OR MOLAL ANALYSIS

$$V = \frac{V_a}{V_t} + \frac{V_b}{V_t} + \frac{V_c}{V_t} + \dots$$

- DALTON'S LAW OF PARTIAL PRESSURE

$$P = P_a + P_b + P_c$$

$$P_x = \frac{V_x}{V_t}(P_t) \rightsquigarrow \text{simply RATIO!} \quad \frac{P_x}{P_t} = \frac{V_x}{V_t}$$

- SPECIFIC HEAT OF THE MIXTURE

$$c_p = \frac{m_a}{m_t} c_{pa} + \frac{m_b}{m_t} c_{pb} + \frac{m_c}{m_t} c_{pc} + \dots$$

$$c_v = \frac{m_a}{m_t} c_{va} + \frac{m_b}{m_t} c_{vb} + \frac{m_c}{m_t} c_{vc} + \dots$$

WHAT IS AMAGAT'S LAW (PARTIAL VOLUME) ??

AMAGAT'S LAW STATES THAT THE EXTENSIVE VOLUME OF A GAS MIXTURE IS EQUAL TO THE SUM OF VOLUMES OF THE K COMPONENT GASES, **IF THE TEMPERATURE T AND THE PRESSURE P REMAIN THE SAME.**

$$V = NV$$

$$V = V_1 + V_2 + V_3 + \dots V_n$$

PROCESSES	CONSTANT	Wnf	Wsf	ΔU	ΔH	Q	ΔS
ISOMETRI ISOCHORIC ISOVOLUMIC ISOVOLUMETRIC	$V=C$	0	$V(P_1-P_2)$	$mc_v\Delta t$	$mc_p\Delta t$	$mc_v\Delta t$	$mc_v \ln\left(\frac{T_2}{T_1}\right)$
ISOBARIC	$P=C$	$P(V_2-V_1)$	0	$mc_v\Delta t$	$mc_p\Delta t$	$mc_p\Delta t$	$mc_p \ln\left(\frac{T_2}{T_1}\right)$
ISOTHERMAL	$T=C$	$P_1V_1 \ln\left(\frac{V_2}{V_1}\right)$ $mRT \ln\left(\frac{V_2}{V_1}\right)$	$P_1V_1 \ln\left(\frac{V_2}{V_1}\right)$ $mRT \ln\left(\frac{V_2}{V_1}\right)$	0	0	$P_1V_1 \ln\left(\frac{V_2}{V_1}\right)$ $mRT_1 \ln\left(\frac{V_2}{V_1}\right)$	$mR \ln\left(\frac{V_2}{V_1}\right)$
ISENTROPIC ADIABATIC	$PV^K=C$	$mc_v\Delta t$ $\frac{P_2V_2-P_1V_1}{1-K}$ $\frac{mR\Delta t}{1-K}$	$k(mc_v\Delta t)$ $k\left(\frac{P_2V_2-P_1V_1}{1-K}\right)$ $k\left(\frac{mR\Delta t}{1-K}\right)$	$-Wnf$	$mc_p\Delta t$	0	0
POLYTROPIC	$PV^n=C$	$\frac{P_2V_2-P_1V_1}{1-n}$ $\frac{mR\Delta t}{1-n}$	$n\left(\frac{P_2V_2-P_1V_1}{1-n}\right)$ $n\left(\frac{mR\Delta t}{1-n}\right)$ $Q-\Delta H$	$mc_v\Delta t$	$mc_p\Delta t$	$mc_n\Delta t$ $c_n = c_v\left[\frac{k-n}{1-n}\right]^a$ REMEMBER THIS!! KANIN	$mc_n \ln\left(\frac{T_2}{T_1}\right)$ $mc_n \ln\left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}}$ $mc_n \ln\left(\frac{V_1}{V_2}\right)^{k-1}$

FOR $PV^n=C$

IF $n=0$, $n=1$, $n=K$, $n=\infty$ | ISOBARIC, ISOTHERMAL, ISENTROPIC, ISOMETRIC ⇝

NOTE:
REPLACE n WITH: 1, 0, K, ∞
EQN: $PV^n=C$

NOTE :

- SAME BOX COLOR MEANS SAME FORMULA/ SIMILAR FORMULA

ADDITIONAL INFO:

FOR ISENTROPIC:

$$\frac{T_1}{T_2}=\left(\frac{V_2}{V_1}\right)^{K-1}=\left(\frac{P_1}{P_2}\right)^{\frac{K-1}{K}}$$

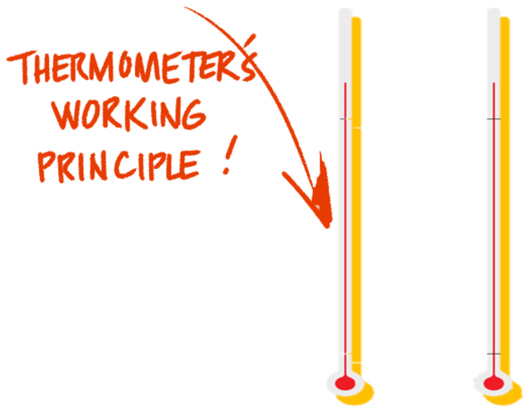
GENERALLY:

- $Wn = Q-\Delta U$
- $Ws = Q-\Delta PE-\Delta KE-\Delta H$

LAWS OF THERMODYNAMICS

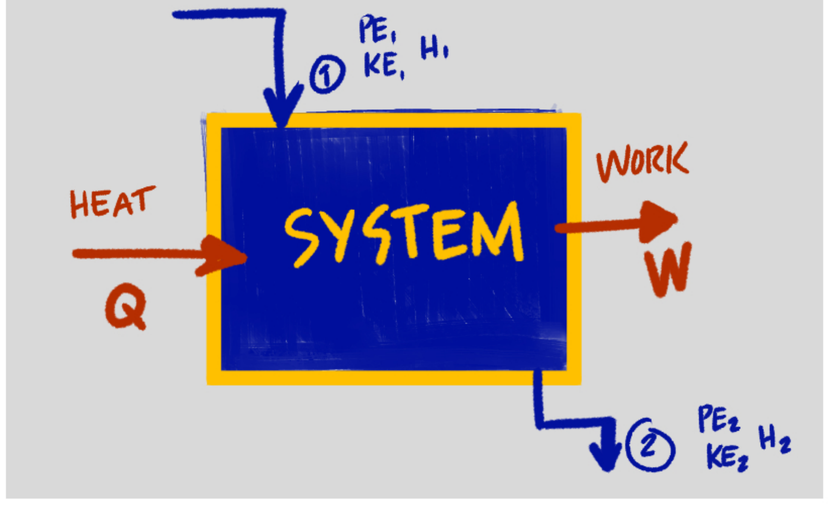
ANY DEVICE THAT VIOLATES EITHER LAW IS CALLED A **PERPETUAL-MOTION MACHINE**

- **ZEROTH LAW**
  - THERMAL EQUILIBRIUM, TEMPERATURE
  - A=B , B=C, THEN A=C



THE ZEROTH LAW WAS FIRST FORMULATED AND LABELED **BY R. H. FOWLER.** AS THE NAME SUGGESTS, ITS VALUE AS A FUNDAMENTAL PHYSICAL PRINCIPLE WAS RECOGNIZED MORE THAN HALF A CENTURY AFTER THE FORMULATION OF THE FIRST AND THE SECOND LAWS OF THERMODYNAMICS. IT WAS NAMED THE ZEROTH LAW SINCE IT SHOULD HAVE PRECEDED THE FIRST AND THE SECOND LAWS OF THERMODYNAMICS.

- **FIRST LAW (CONSERVATION OF ENERGY)**
  - ENERGY CANNOT BE CREATED NOR DESTROYED, IT CAN ONLY BE **CONVERTED INTO ANOTHER FORM OF ENERGY**



□ OPEN SYSTEM (STEADY-FLOW)

$$Q = W_s + \Delta H$$

□ CLOSED SYSTEM (NON-FLOW)

$$Q = W_n + \Delta U$$

$$\Delta PV = 0$$

- **SECOND LAW (ENTROPY)**
  - ENTROPY CAN BE VIEWED AS A MEASURE OF **MOLECULAR DISORDER**, OR MOLECULAR RANDOMNESS.
  - THE SECOND LAW OF THERMODYNAMICS STATES THAT PROCESSES OCCUR IN A CERTAIN DIRECTION, NOT IN ANY DIRECTION.
  - WORK CAN BE CONVERTED TO HEAT DIRECTLY, BUT HEAT CAN BE CONVERTED TO WORK ONLY BY SOME DEVICES CALLED HEAT ENGINES.

REVERSIBILITY AND IRREVERSIBILITY:

-A REVERSIBLE PROCESS IS DEFINED AS A PROCESS THAT CAN BE REVERSED WITHOUT LEAVING ANY TRACE ON THE SURROUNDINGS – THIS IS MERELY IDEALIZATION (THEORETICAL LIMITS).

IRREVERSIBILITIES:

- FRICTION
- UNRESTRAINED EXPANSION OF GAS
- HEAT TRANSFER

ADIABATIC VS. ISENTROPIC

ADIABATIC PROCESS CAN EITHER BE REVERSIBLE AND IRREVERSIBLE BUT ISENTROPIC PROCESS IS SPECIFICALLY A REVERSIBLE ADIABATIC PROCESS ITSELF.

ADIABATIC VS. ISOTHERMAL

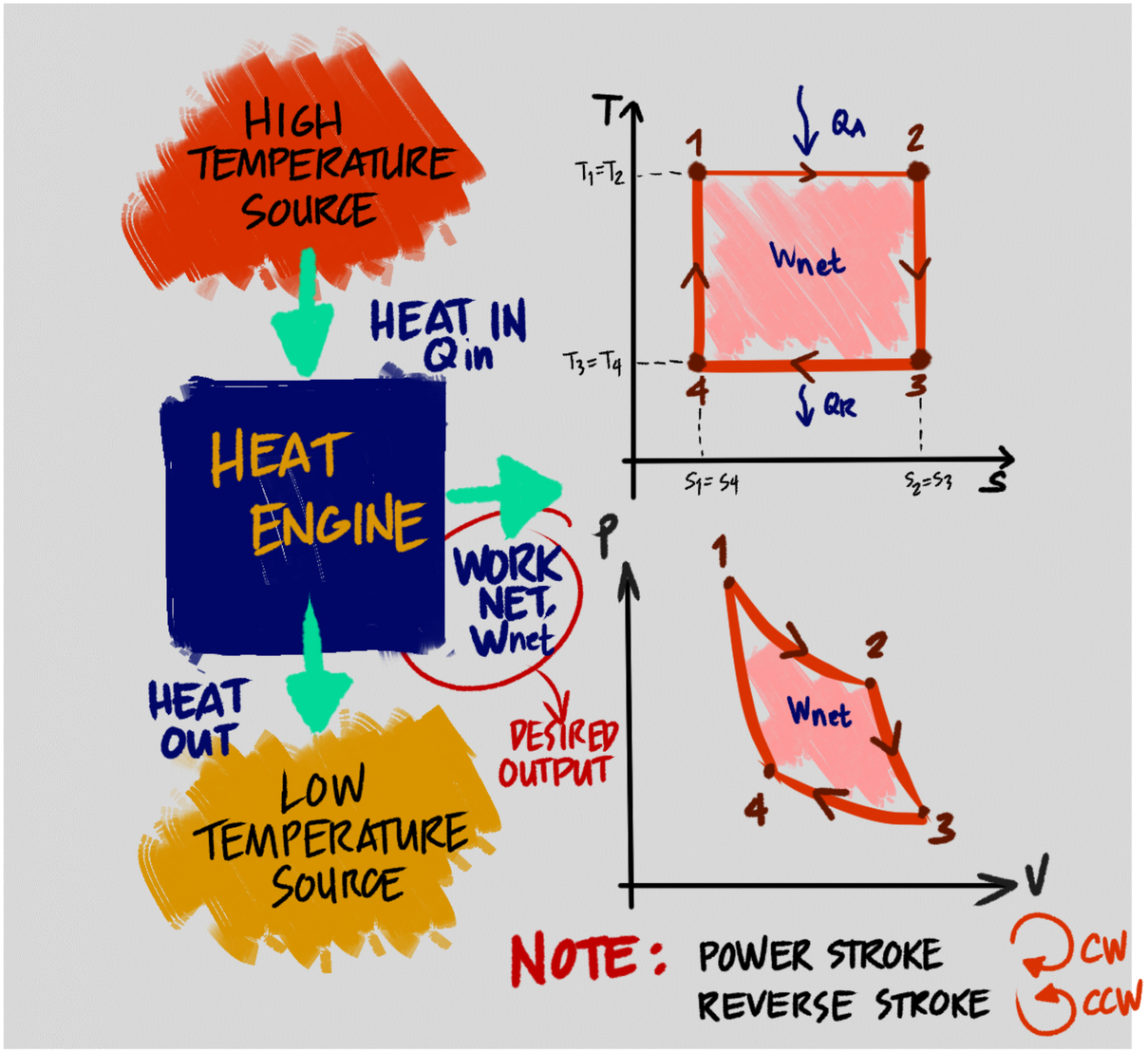
IN AN ISOTHERMAL PROCESS, HEAT CAN BE ADDED OR RELEASED FROM THE SYSTEM JUST TO KEEP THE SAME TEMPERATURE WHILE IN AN ADIABATIC PROCESS, THERE'S NO HEAT ADDED OR RELEASED BECAUSE MAINTAINING CONSTANT TEMPERATURE WILL NOT MATTER.

KELVIN - PLANCK STATEMENT (HEAT ENGINE)	CLAUSIUS – STATEMENT (HEAT PUMP)
THAT NO HEAT ENGINE CAN PRODUCE A NET AMOUNT OF WORK WHILE EXCHANGING HEAT WITH A SINGLE RESERVOIR ONLY.	NO DEVICE CAN TRANSFER HEAT A COOLER BODY TO A WARMER ONE WITHOUT LEAVING AN EFFECT ON THE SURROUNDINGS
IMPOSSIBLE FOR HEAT IN = WORK (IMPOSSIBLE! $Q_{in} = W_{ork}$)	IMPOSSIBLE TO CONSTRUCT A HEAT PUMP, THAT OPERATES WITHOUT AN INPUT WORK

- **THIRD LAW**
  - ENTROPY OF A SYSTEM APPROACHES A CONSTANT VALUE AS THE TEMPERATURE APPROACHES ABSOLUTE ZERO.

CARNOT CYCLE HEAT ENGINE

CARNOT CYCLE IS COMPOSED OF FOUR REVERSIBLE PROCESSES—TWO ISOTHERMAL AND TWO ADIABATIC—AND IT CAN BE EXECUTED EITHER IN A CLOSED OR A STEADYFLOW SYSTEM.



1-2 REVERSIBLE ISOTHERMAL EXPANSION
2-3 REVERSIBLE ADIABATIC EXPANSION
3-4 REVERSIBLE ISOTHERMAL COMPRESSION
4-1 REVERSIBLE ADIABATIC COMPRESSION

COMPUTATIONS:

☐ CYCLE EFFICIENCY

$$e = \frac{W_{net}}{Q_A} = 1 - \frac{Q_R}{Q_A}$$

$$e = \frac{T_H - T_L}{T_H} = 1 - \frac{T_L}{T_H}$$

NOTE:
T_H = HIGH TEMP.
T_L = LOW TEMP.

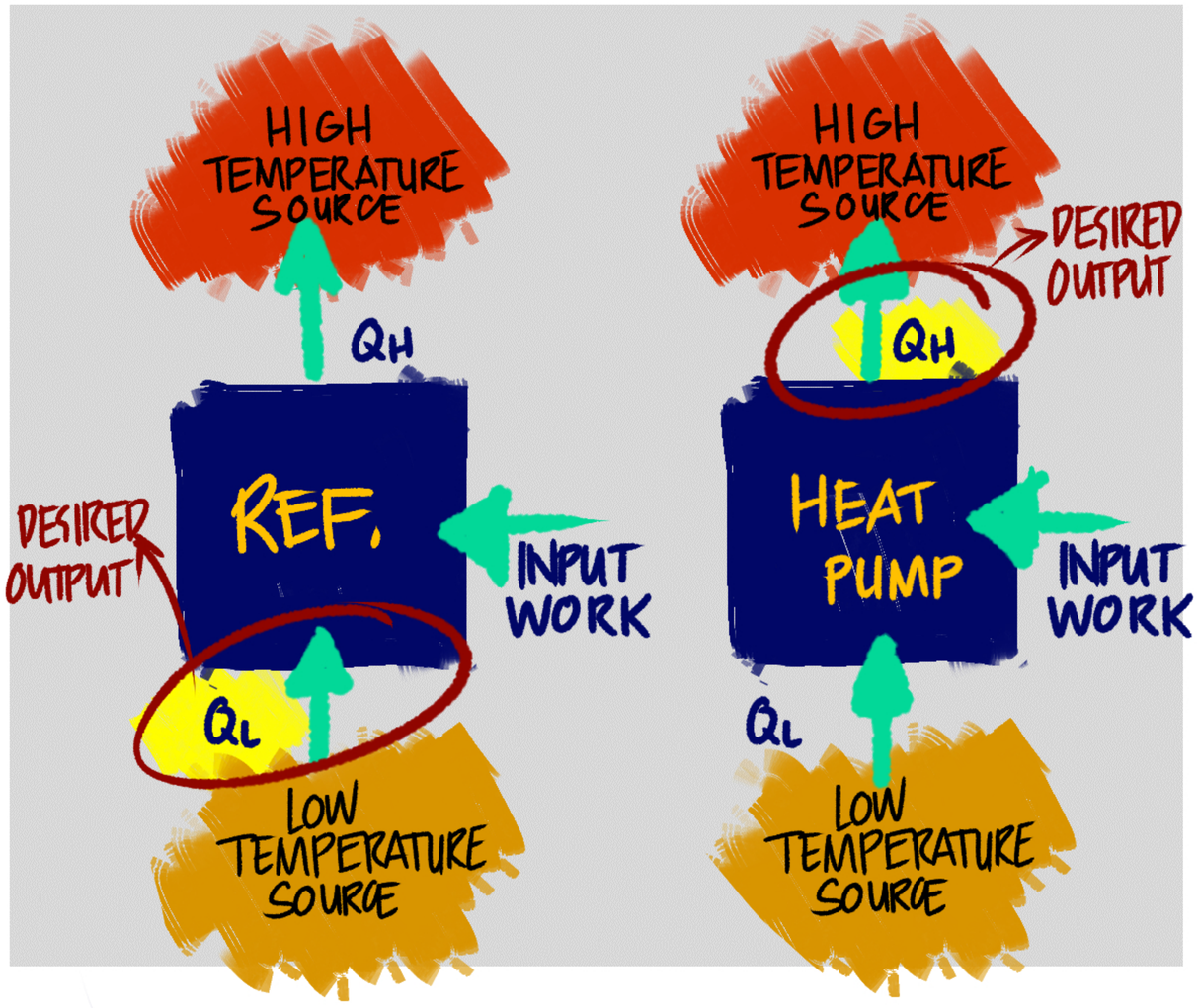
☐ HEAT & TEMPERATURE RELATIONS

▷ HEAT & TEMPERATURE ARE DIRECTLY PROPERTIONAL

$$\frac{Q_R}{Q_A} = \frac{Q_L}{Q_H} = \frac{T_L}{T_H} = \frac{T_2}{T_1}$$

CARNOT HEAT PUMP AND REFRIGERATOR

REFRIGERATORS AND HEAT PUMPS OPERATE ON THE SAME CYCLE BUT DIFFER IN THEIR OBJECTIVES.



HEAT PUMP

$$COP_{HP} = \frac{Q_H}{Q_H - Q_L}$$ → DESIRED OUTPUT!

$$COP_{HP} = \frac{T_H}{T_H - T_L}$$

ALSO;

$$COP_{HP} = COP_R + 1$$

REFRIGERATOR

$$COP = \frac{\text{DESIRED OUTPUT}}{\text{REQUIRED INPUT}}$$

$$COP_R = \frac{Q_L}{Q_H - Q_L}$$ → DESIRED OUTPUT!!

$$COP_R = \frac{T_L}{T_H - T_L}$$

NOTE ; ONLY DIFFERENCE BETWEEN HP & REF IS DESIRED OUTPUT

THE PERFORMANCE IS OFTEN EXPRESSED IN TERMS OF THE *ENERGY EFFICIENCY RATIO (EER) OR SEASONAL ENERGY EFFICIENCY RATIO (SEER)* DETERMINED BY TESTING STANDARDS.

SEER IS THE RATIO THE TOTAL AMOUNT OF HEAT REMOVED BY AN AIR CONDITIONER OR HEAT PUMP DURING A NORMAL COOLING SEASON (IN BTU) TO THE TOTAL AMOUNT OF ELECTRICITY CONSUMED (IN WATT-HOURS, WH), AND IT IS A MEASURE OF *SEASONAL PERFORMANCE OF COOLING EQUIPMENT.*

EER, ON THE OTHER HAND, IS A MEASURE OF THE *INSTANTANEOUS ENERGY EFFICIENCY*, AND IS DEFINED AS THE RATIO OF THE RATE OF HEAT REMOVAL FROM THE COOLED SPACE BY THE COOLING EQUIPMENT TO THE RATE OF ELECTRICITY CONSUMPTION IN STEADY OPERATION.

$$EER = 3.412 COP_R$$

FLUID MECHANICS

- **FLUID STATICS** – FLUIDS AT REST
- **FLUID KINEMATICS** – VELOCITIES, STREAMLINES, W/OUT CONSIDERING FORCES OR ENERGY
- **HYDRODYNAMICS** – RELATIONS BETWEEN VELOCITIES AND ACCELERATIONS AND THE FORCES EXERTED ON FLUIDS IN MOTION

WHAT IS A FLUID??

– SUBSTANCE THAT CANNOT MAINTAIN ITS OWN SHAPE BUT TAKES THE SHAPE OF ITS CONTAINER – E.G. – **LIQUIDS AND GASSES**

CHARACTERISTICS	LIQUIDS	GASES
COMPRESSIBILITY	INCOMPRESSIBLE	COMPRESSIBLE
RESISTANCE TO MOTION	RESIST CHANGES IN VELOCITY BECAUSE OF VISCOSITY	LOW VISCOUS FLUIDS
MOLECULAR SPACING	RELATIVELY CLOSE, LOW KINETIC ENERGY	RELATIVELY FAR APART, HIGH KINETIC ENERGY
PRESSURE	PRESSURE EXERTED BY A FLUID ON ANY SOLID SURFACE IS ALWAYS NORMAL TO THAT SURFACE	
SHEAR RESISTANCE	CANNOT SUPPORT SHEAR FORCES	
SHAPE AND VOLUME	FIXED VOLUMES	TAKE ON VOLUMES OF CONTAINER
	TAKES THE SHAPES OF THE CONTAINER	

TYPES OF FLUIDS

A. IDEAL FLUIDS

- NO VISCOSITY, INCOMPRESSIBLE, NO RESISTANCE TO SHEAR, NO EDDY CURRENTS, AND NO FRICTION BETWEEN MOVING SURFACES

B. REAL FLUID

- COMPRESSIBLE, NON-UNIFORM VELOCITY DISTRIBUTIONS, AND HAVE FRICTION AND TURBULENCE IN FLOW

I. NEWTONIAN FLUIDS

– (AIR, WATER, GASES, AND STEAMS, ETC)

- VISCOUS REAL FLUID WHOSE STRESSES ARE **A LINEAR FUNCTION OF THE FLUID STREAM**

II. NON – NEWTONIAN FLUIDS

– (GELS, ELECTROLYTE SOLUTIONS, SLURRIES, PASTES)

QUESTION!!!

WHAT IS EDDY CURRENT??

-AN EDDY IS THE SWIRLING OF A FLUID AND THE REVERSE CURRENT CREATED WHEN THE FLUID IS IN A **TURBULENT FLOW REGIME**

WHAT IS A VORTEX??

-A VORTEX (PLURAL VORTICES/VORTEXES) IS A REGION IN A FLUID IN WHICH THE FLOW **REVOLVES AROUND AN AXIS LINE**, WHICH MAY BE STRAIGHT OR CURVED.

FLUID PROPERTIES

1. SPECIFIC WEIGHT

$$\gamma = \frac{W}{V}$$

H_2O CONSTANTS:

$\gamma_w = 9.81\ kN/m^3 = 62.4\ lb/ft^3$

2. MASS

- AMOUNT OF MATTER

$$m = W/g$$

VALUES OF GRAVITY:

$g = 9.81\ m/s^2 = 32.2\ ft/s^2$

3. DENSITY

$$\rho = \frac{MASS}{VOLUME}$$

COMMON DENSITY VALUES:

$\rho_w = 1000\ kg/m^3 = 62.4\ lb/ft^3$

TEMPERATURE OF STD. VALUES:

ENGINEERS: 15.6°C PHYSICISTS: 4°C

4. SPECIFIC GRAVITY

$$Sg = \frac{\gamma_{FLUID}}{\gamma_{std.}} = \frac{\rho_{FLUID}}{\rho_{std.}}$$

STANDARDS:

WATER ($\rho = 1000\ kg/m^3$) - FOR LIQUIDS

AIR ($\rho = 1.2\ kg/m^3$) - FOR GASES

SG OF COMMON FLUIDS:

WATER	1.0
SEA WATER	1.03
MERCURY	13.6

5. SPECIFIC VOLUME

$$v = \frac{VOLUME}{MASS} = \frac{1}{\rho}$$ (INVERSE OF DENSITY)

COMMON CONVERSIONS:

MASS:

- 1 kg = 2.21 lbm
- 1 lbm = 16 oz
- 1 SLUG = 32.2 lb
- 1 TONNE = 1 MT = 1000 kg
- 1 SHORT TON = 2000 lbm
- 1 LONG TON = 2240 lbm

VOLUME:

- 1 GALLON = 3.785 L
- 7.48 GALLON = 1 ft^3
- 1 bbl (BARREL) = 42 GAL
- 1 m^3 = 1000 L

- 1 GANTA = 8 CHUPA = 3 LITERS

FLUID PROPERTIES (CONTINUATION)

6. COEFFICIENT OF COMPRESSIBILITY

- **BULK MODULUS OF ELASTICITY**, REPRESENTS THE CHANGE IN PRESSURE CORRESPONDING TO A FRACTIONAL CHANGE IN VOLUME OR DENSITY OF THE FLUID WHILE **TEMPERATURE IS CONSTANT**.

$$k \simeq -\frac{\Delta P}{\Delta V/V} \simeq \frac{\Delta P}{\Delta \rho/\rho} \quad (\text{TEMPERATURE} = C)$$

7. COEFFICIENT OF VOLUME EXPANSION

- **VOLUME EXPANSIVITY**, REPRESENTS THE VARIATION OF THE DENSITY OF A FLUID WITH TEMPERATURE AT CONSTANT PRESSURE

$$\beta \simeq \frac{\Delta V/V}{\Delta T} = -\frac{\Delta \rho/\rho}{\Delta T} \quad (\text{PRESSURE} = C)$$

8. ISOTHERMAL COMPRESSIBILITY

- IS THE **INVERSE OF THE COEFFICIENT OF COMPRESSIBILITY** (BULK MODULUS OF ELASTICITY)

$$\alpha = \frac{1}{k} \; ; \; 1/Pa$$

9. VARIATION OF DENSITY WITH TEMPERATURE AND PRESSURE

- THE FRACTIONAL **CHANGE IN DENSITY (OR VOLUME) DUE TO CHANGES IN PRESSURE AND TEMPERATURE** CAN BE EXPRESSED APPROXIMATELY AS:

$$\frac{\Delta V}{V} = \frac{\Delta \rho}{\rho} \cong \beta \Delta T = \alpha \Delta P$$

10. DYNAMIC VISCOSITY

- **ABSOLUTE VISCOSITY**, MEASURES A FLUID'S RESISTANCE TO FLOW WHEN AN EXTERNAL FORCE IS APPLIED.
- VISCOSITY RELATED TO THE EXTERNAL FORCE APPLIED TO **NON-NEWTONIAN FLUIDS.**

11. KINEMATIC VISCOSITY

- IS THE MEASURE OF A FLUID'S INHERENT RESISTANCE TO FLOW WHEN NO EXTERNAL FORCE, EXCEPT GRAVITY, IS ACTING ON IT.
- : INHERENT VISCOSITY OF **NEWTONIAN FLUIDS**, THAT DOES NOT CHANGE WITH A CHANGE IN APPLIED FORCE.

VISCOSITY	FORMULA	UNITS AND CONVERSIONS
DYNAMIC (ABSOLUTE)	$M_d = \frac{F/A}{dv/dy}$ F/A = SHEAR STRESS dv/dy = SHEAR STRAIN	ENGLISH: 1 REYN = 1 $\frac{lb-sec}{in^2}$ METRIC: 1 POISE = 1 $\frac{DYNE-SEC}{cm^2}$ = 0.1 Pa-sec NOTE: 1 DYNE = 1 $\frac{GRAM-cm}{SEC^2}$
KINEMATIC	$M_k = \frac{M_d}{\rho}$	ENGLISH: ft^2/s METRIC: m^2/s 1 STOKE: 1 cm^2/s

DYNAMIC VS. KINEMATIC VISCOSITY?

- **DYNAMIC VISCOSITY** (ALSO KNOWN AS ABSOLUTE VISCOSITY) IS THE MEASUREMENT OF THE FLUID'S INTERNAL RESISTANCE TO FLOW WHILE **KINEMATIC VISCOSITY** REFERS TO THE RATIO OF DYNAMIC VISCOSITY TO DENSITY.
- **TWO FLUIDS WITH THE SAME DYNAMIC VISCOSITIES CAN HAVE VERY DIFFERENT KINEMATIC VISCOSITIES DEPENDING ON DENSITY AND VICE VERSA.**

12. SURFACE TENSION

- THE **PULLING EFFECT ON THE LIQUID MOLECULES** AT AN INTERFACE CAUSED BY THE ATTRACTIVE FORCES OF MOLECULES PER UNIT LENGTH IS CALLED SURFACE TENSION.
- SURFACE TENSION IS THE **TENDENCY OF LIQUID SURFACES TO SHRINK INTO THE MINIMUM SURFACE AREA POSSIBLE.** SURFACE TENSION **ALLOWS INSECTS, USUALLY DENSER THAN WATER, TO FLOAT AND SLIDE ON A WATER SURFACE.**
- **COHESIVE FORCES** ARE RESPONSIBLE FOR SURFACE TENSION

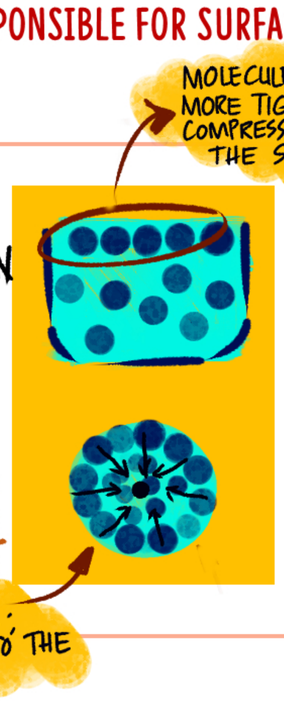
SOAP BUBBLE: $\sigma = \frac{PR}{4}$

LIQUID BUBBLE: $\sigma = \frac{PR}{2}$

LIQUID JET: $\sigma = \frac{PR}{4}$

WHERE:
σ = SURFACE TENSION
$P = (P_{in} - P_{out})$

CONSTANTS:
$\sigma_w @ 0°C = 0.076 \frac{N}{m}$
$\sigma_w @ 100°C = 0.059 \frac{N}{m}$



13. CAPILLARY ACTION (CAPILLARITY)

- **THE RISE OR FALL OF A LIQUID IN A SMALL-DIAMETER** TUBE INSERTED INTO THE LIQUID DUE TO SURFACE TENSION IS CALLED THE CAPILLARY EFFECT.

ADHESION

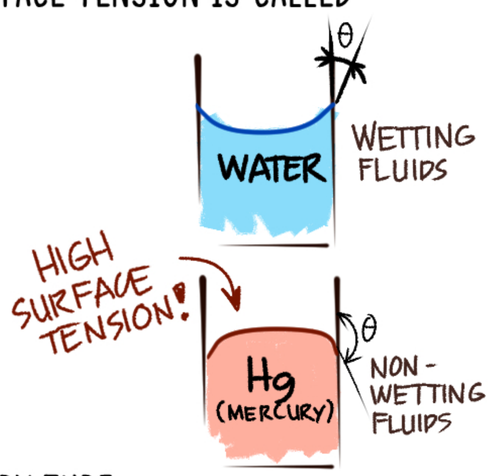
- DIFFERENT SUBSTANCE
- ENABLES TO RESIST TENSILE STRESS

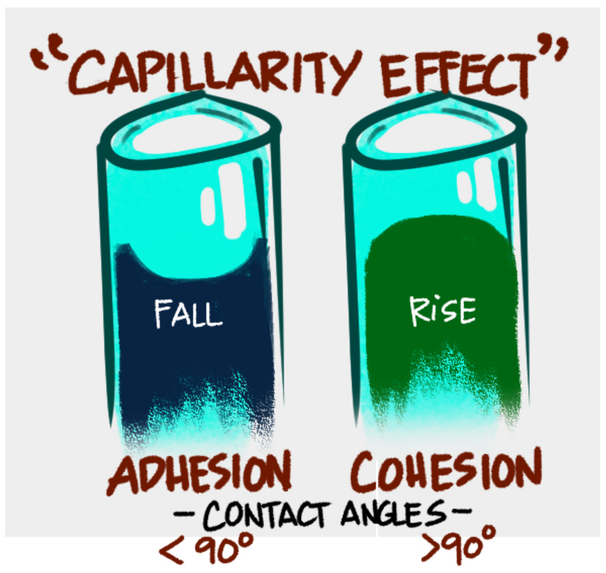
COHESION

- SAME SUBSTANCE
- ENABLE TO ADHERE TO ANOTHER BODY

MENISCUS

- CURVE SURFACE OF LIQUID IN A CAPILLARY TUBE





$$h = \frac{4\sigma\cos\theta}{\gamma d}$$

IMPORTANT FOR TUBES SMALLER THAN 3/8 in (9.5 mm) Ø

MERCURY IS A NON WETTING LIQUID AS IT DOES NOT WET THE SURFACE IN WHICH IT IS KEPT AS THE COHESION FORCES WITHIN THE DROPS ARE STRONGER THAN THE ADHESIVE FORCES BETWEEN THE DROPS AND THE SURFACE. **BECAUSE OF ITS HIGH SURFACE TENSION IT DOESN'T WET MOST SURFACES**

14. MACH NUMBER

- MACH NUMBER IS THE RATION OF THE ACTUAL SPEED OF THE FLUID TO THE SPEED OF SOUND **AT THE SAME STATE.**

$$M.N. = \frac{V_o}{V_s}$$

V_o = VELOCITY OF THE OBJECT
V_s = VELOCITY OF SOUND

PREREQUISITE:

THE VELOCITY AT WHICH AN INFINITESIMALLY SMALL PRESSURE WAVE TRAVELS THROUGH A MEDIUM IS THE SPEED OF SOUND. FOR AN IDEAL GAS IT IS EXPRESSED AS:

VELOCITY OF SOUND IN GAS:

$$V_s = \sqrt{kRT}$$

FOR AIR: USE $k = 1.4$

VELOCITY OF SOUND IN LIQUIDS;

$$V_s = \sqrt{\frac{E}{\rho}}$$

WHERE:
- E – BULK'S MODULUS OF ELASTICITY
- WATER:
  $E = 2.1 \times 10^6$ kPa
  $\rho = 1000$ kg/m³

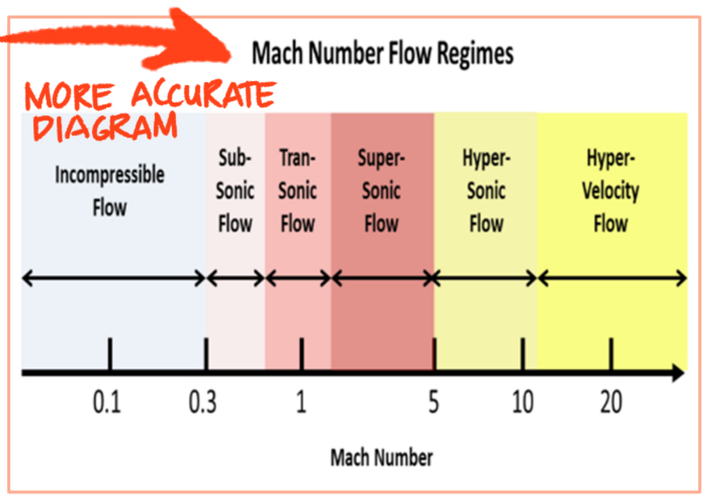
SUBSONIC	<1
SONIC	=1
SUPERSONIC	>1
HYPERSONIC	>>1 EXTREMELY HIGH
TRANSONIC	≈1

SONIC BOOM
PHENOMENON WHICH OCCUR DUE TO TRANSONIC

WHY IS THERE A NEED FOR MACH NUMBER??

-MACH NUMBER IS PRIMARILY USED TO DETERMINE THE APPROXIMATION WITH WHICH A FLOW CAN BE TREATED AS AN INCOMPRESSIBLE FLOW.

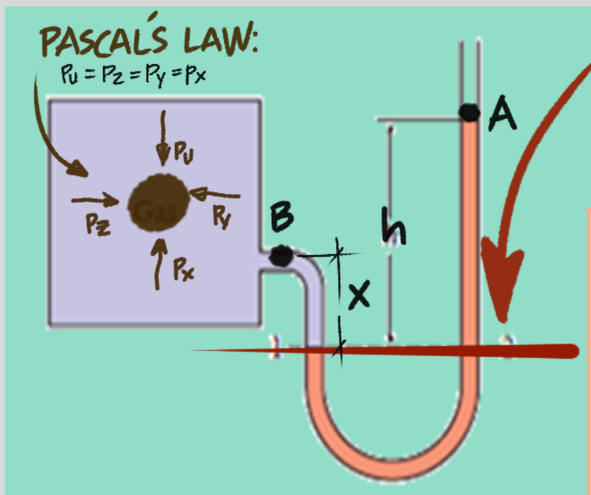
MORE ACCURATE DIAGRAM



FLUID STATICS

PASCAL'S LAW:

$P_U = P_Z = P_Y = P_X$



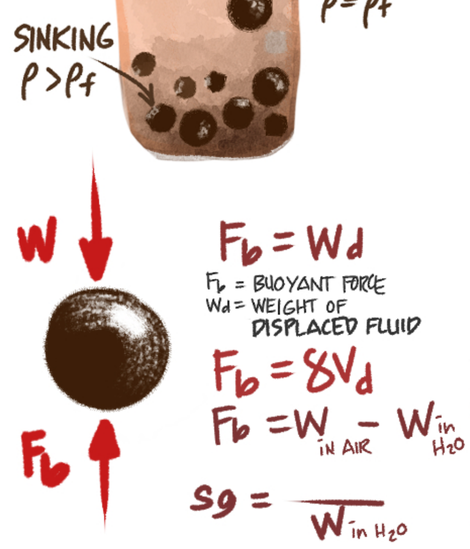
FIND REFERENCE POINT

= THIS SERVES AS AN EQUAL SIGN.

EXAMPLE: $P_A + \gamma_h h = P_B + \gamma_x x$

$$P = \frac{F}{A}$$

\+ GOING DOWN − GOING UP



BUOYANCY

FORCE THAT TENDS TO LIFT THE BODY IS CALLED **BUOYANT FORCE**

$F_b = W_d$

F_b = BUOYANT FORCE
W_d = WEIGHT OF DISPLACED FLUID

$F_b = \gamma V_d$

$F_b = W_{\text{IN AIR}} - W_{\text{in } H_2O}$

$$sg = \frac{}{W_{\text{in } H_2O}}$$

ARCHIMEDES PRINCIPLE:

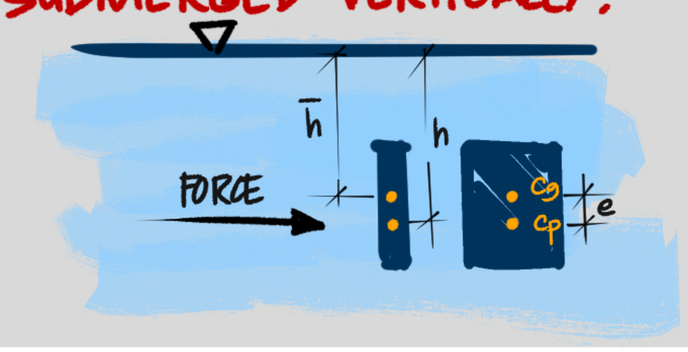
CHANGE TO EITHER V, A, H

$$\frac{V_{SUBMERGED}}{V_{BODY}} = \frac{SG_{SUBMERGED}}{SG_{BODY}} = \frac{\rho_{SUBMERGED}}{\rho_{BODY}}$$

NOTE: COULD BE VOLUME, AREA, HEIGHT!

HYDROSTATIC FORCE ON PLANE SURFACES

SUBMERGED VERTICALLY:

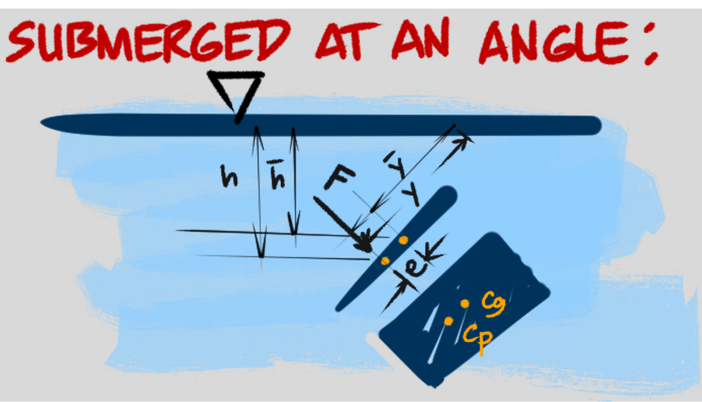


$$F = \gamma \bar{h} A_p$$

$$h = \bar{h} + e$$

$$e = \frac{I_g}{A\bar{h}}$$

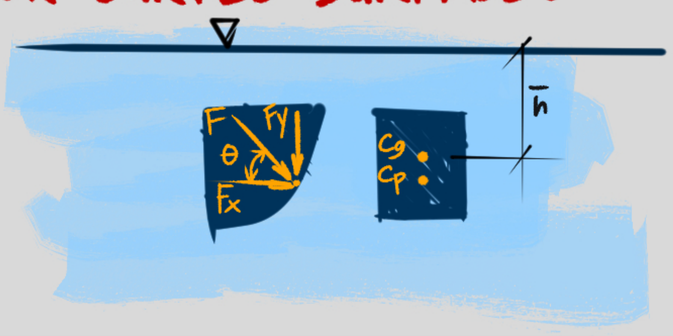
SUBMERGED AT AN ANGLE:



$$\bar{h} = \bar{y}\sin\theta \qquad \bar{y} = \frac{\bar{h}}{\sin\theta}$$

$$F = \gamma \bar{y} A_p$$

FOR CURVED SURFACE:



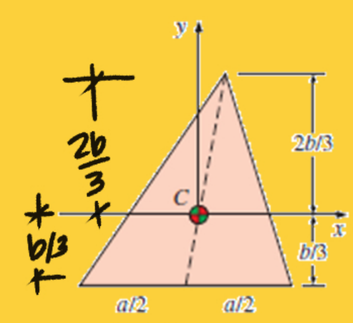
$$F_x = \gamma \bar{h} A_p$$

$$F_y = \gamma V_D$$

$$F = \sqrt{F_x^2 + F_y^2}$$

$$\theta = \tan^{-1}\left(\frac{F_y}{F_x}\right)$$

COMMON I_g & AREA:



RECTANGLE
$I_g = ab^3/12$

CIRCLE
$I_g = \pi R^4/4$

TRIANGLE
$I_g = ab^3/36$
$A = \frac{1}{2}ab$

CIRCLE
$I_g = 0.109757R^4$
$A = \frac{\pi}{2}R^2$

ELLIPSE
$I_g = \frac{\pi a b^3}{4}$

SEMI-ELLIPSE
$I_g = 0.109757ab^3$
$A = \frac{\pi}{2}ab$

FLUID FLOW IN PIPES

1. CONTINUITY EQUATION

$m_1 = m_2$

FOR COMPRESSIBLE FLUIDS = $\rho_1 A_1 V_1 = \rho_2 A_2 V_2$

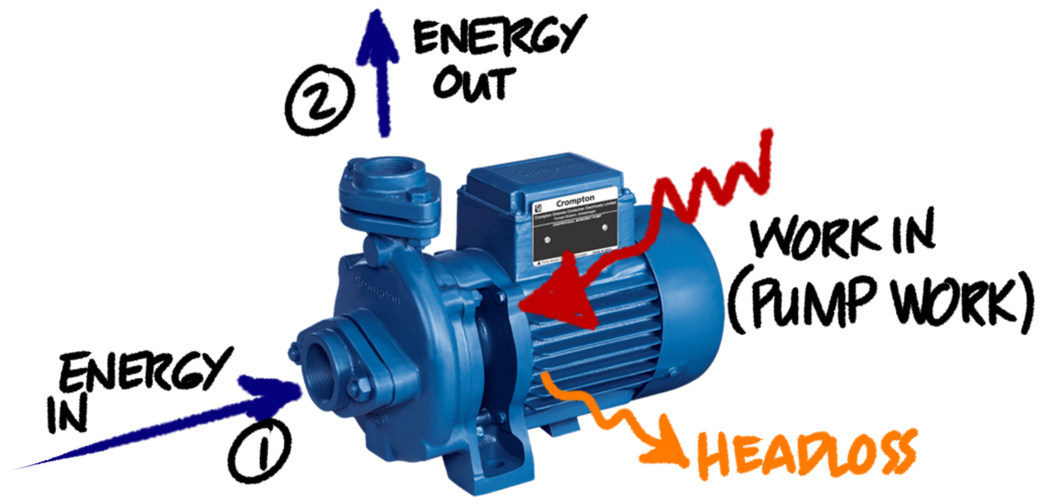
FOR INCOMPRESSIBLE FLUIDS = $A_1 V_1 = A_2 V_2$

2. ENERGY EQUATION (BERNOULLI'S)

- EQUATION WITH PIPE

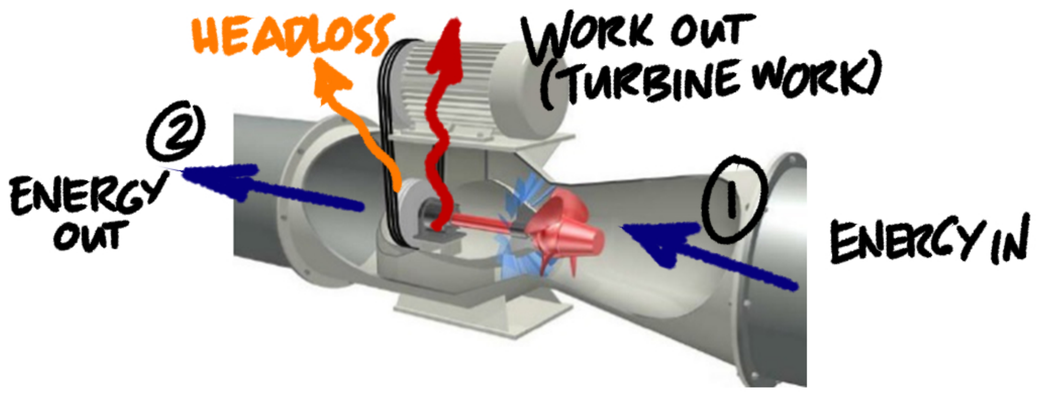
$$\frac{V_1^2}{2g} + \frac{P_1}{\gamma} + Z_1 = \frac{V_2^2}{2g} + \frac{P_2}{\gamma} + Z_2 + H_{L(1-2)}$$

- EQUATION WITH PUMP



$$\frac{V_1^2}{2g} + \frac{P_1}{\gamma} + Z_1 + W_p = \frac{V_2^2}{2g} + \frac{P_2}{\gamma} + Z_2 + H_{L(1-2)}$$

- EQUATION WITH TURBINE



$$\frac{V_1^2}{2g} + \frac{P_1}{\gamma} + Z_1 = \frac{V_2^2}{2g} + \frac{P_2}{\gamma} + Z_2 + H_{L(1-2)} + W_T$$

3. TYPES OF FLOW

A. LAMINAR FLOW

- LAMINAR FLOW IS CHARACTERIZED BY FLUID PARTICLES FOLLOWING SMOOTH PATHS IN LAYERS, WITH EACH LAYER MOVING SMOOTHLY PAST THE ADJACENT LAYERS WITH LITTLE OR NO MIXING

B. TURBULENT FLOW

- TURBULENCE OR TURBULENT FLOW IS FLUID MOTION CHARACTERIZED BY CHAOTIC CHANGES IN PRESSURE AND FLOW VELOCITY.

1. LAMINAR FLOW | $Re < 2000$
2. TURBULENT FLOW | $Re > 4000$

TRANSITION FLOW $(2000 < Re < 4000)$

4. REYNOLD'S NUMBER

- DIMENSIONLESS NUMBER WHICH IS THE RATIO OF THE FORCES OF INERTIA TO VISCOUS FORCES (KINEMATIC) OF THE FLUIDS.

$$N_R = \frac{\text{FORCES OF INERTIA}}{\text{VISCOUS FORCES}} \quad \Big| \quad N_R = \frac{VD\rho}{\mu_d} = \frac{VD}{\mu_k}$$

D = DIAMETER
V = VELOCITY

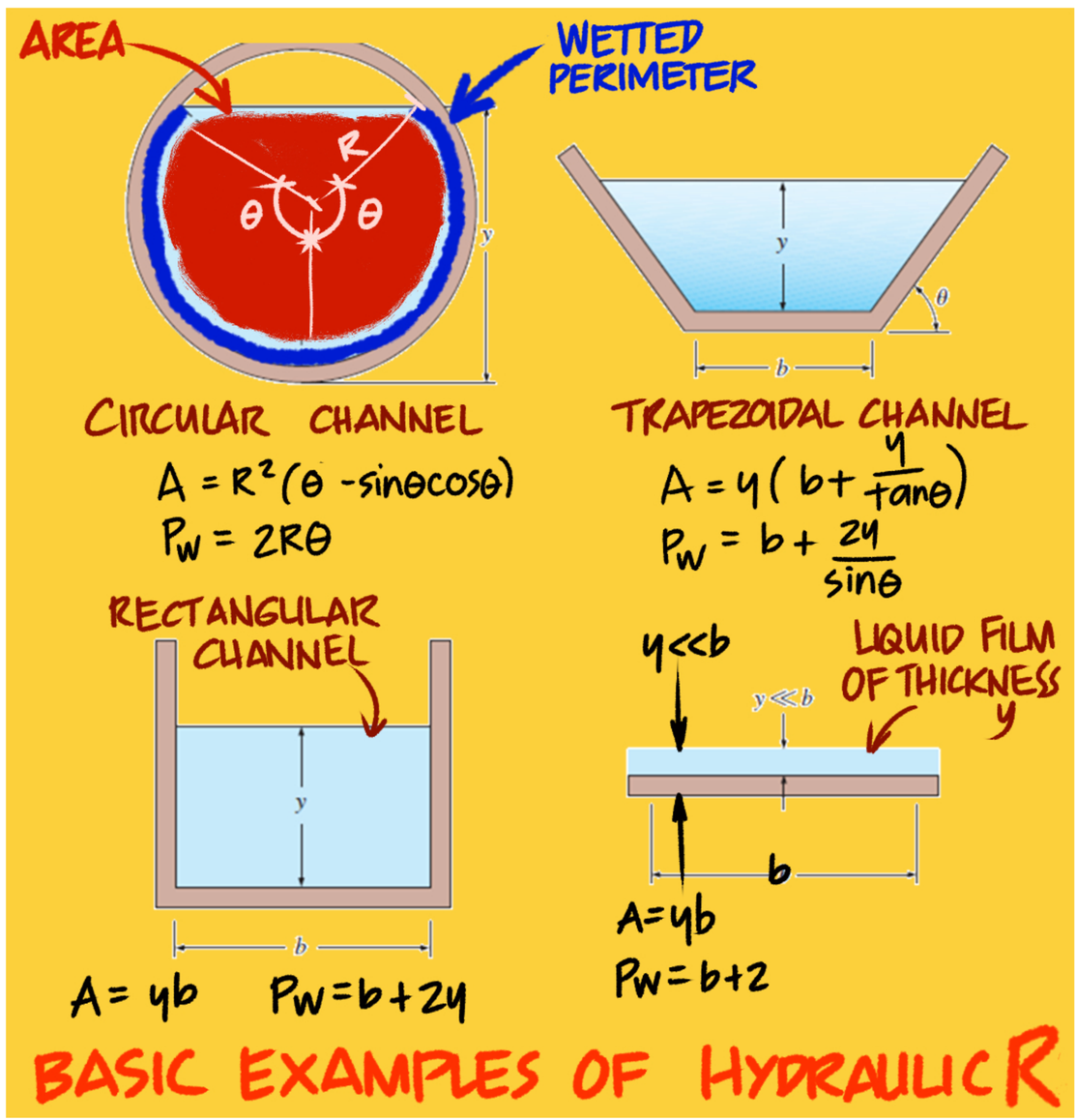
μ_d = ABSOLUTE VISCOSITY ; μ_k = KINEMATIC

HYDRAULIC RADIUS (FOR NON-CIRCULAR SECTIONS)

$$N_R = \frac{V(4R)}{\mu_k}$$

NOTE: $D = 4R$ ← R = HYDRAULIC RADIUS

$$R = \frac{\text{AREA}}{\text{WETTED PERIMETER}}$$



5. MAJOR HEAD LOSS

A. DARCY-WEISBACH EQUATION (TURBULENT)

$$h = f\left(\frac{L}{D}\right)\left(\frac{V^2}{2g}\right)$$

A. MORSE FORMULA

$$h = f\left(\frac{L}{D}\right)\left(\frac{2V^2}{g}\right)$$

MORSE IS FOR (FOUR) DARCY!!

MORSE = 4DARCY

OTHER MAJOR HEAD LOSS FORMULA!!

☐ FOR LAMINAR

- HAGEN-POISEUILLE

$$h_f = \frac{32\mu_d LV}{\gamma D^2}$$

☐ FOR TURBULENT FLOW

- MANNY-CHEZY

$$h_f = \frac{6.35n^2 LV^2}{D^{4/3}}$$

- HAZEN-WILLIAMS

$$h_f = \frac{10.67LQ^{1.85}}{C^{1.85}D^{4.87}}$$

FLUID FLOW IN PIPES (CONT.)

6. COEFFICIENT OF FRICTION

FOR LAMINAR FLOW

$$f = \frac{64}{N_R}$$

FOR TURBULENT FLOW

$$f = \frac{0.316}{\sqrt[4]{N_R}}$$

7. ENERGY LOSS DUE TO FRICTION

FOR LAMINAR FLOW

$$E_f = f\left(\frac{L}{D}\right)\left(\frac{V^2}{2}\right)$$

FOR TURBULENT FLOW

HEADLOSS CAN BE CONVERTED TO HEAD LOSS

$$\Delta P = h_L \gamma$$

8. MINOR HEAD LOSS

$$h_{MINOR} = k\left(\frac{V^2}{2g}\right)$$

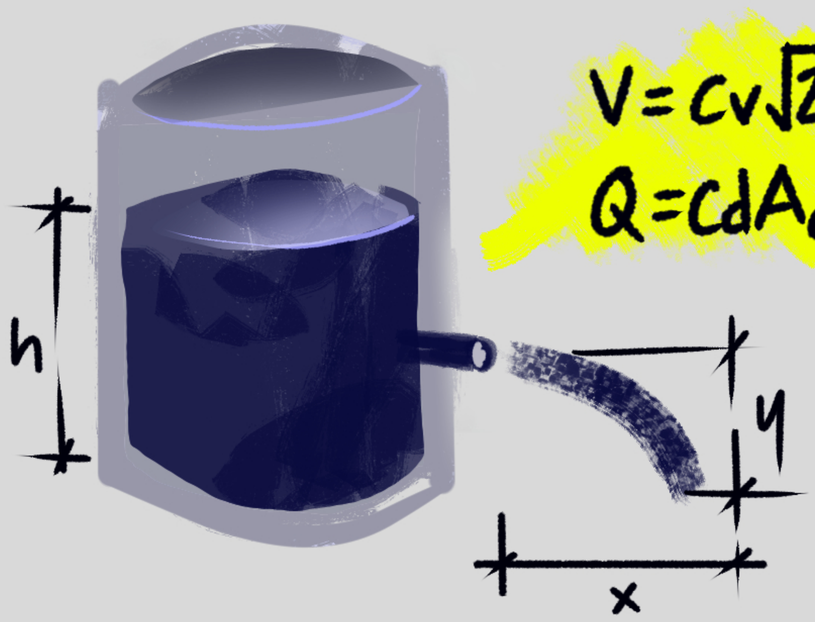
9. PIPE ARRANGEMENT

SET UP	FIGURE	FLOW	HEAD
SERIES		$Q = Q_1 = Q_2$ EQUAL	$H_{L_1} = H_{L_1} + H_{L_2}$ ADDITIVE
PARALLEL		$Q = Q_1 + Q_2 \cdots$ ADDITIVE	$H_L = H_{L_1} + H_{L_2}$ EQUAL

ORIFICES

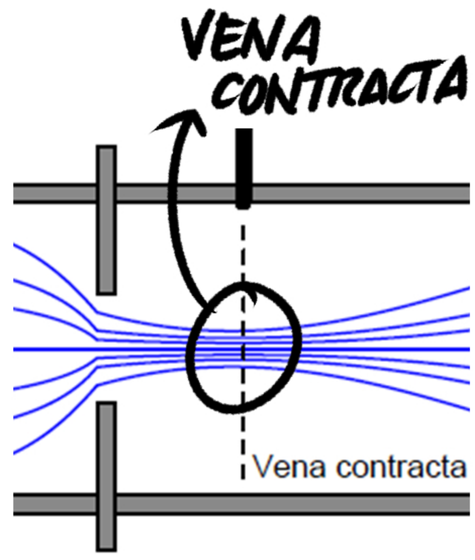
- A SMALL OPENING WHERE LIQUID FLOWS

ORIFICE STEADY FLOW



$$V = C_v\sqrt{2gh}$$
$$Q = C_d A_o \sqrt{2gh}$$

NOTE:
THEORETICAL
$C_d = 1.0$
$C_v = 1.0$



A_o = ORIFICE AREA
C_c = CONTRACTION COEFF.

VENA CONTRACTA

- THE SMALLEST CROSS SECTIONAL AREA OF THE ORIFICE

$$A = C_c A_o$$

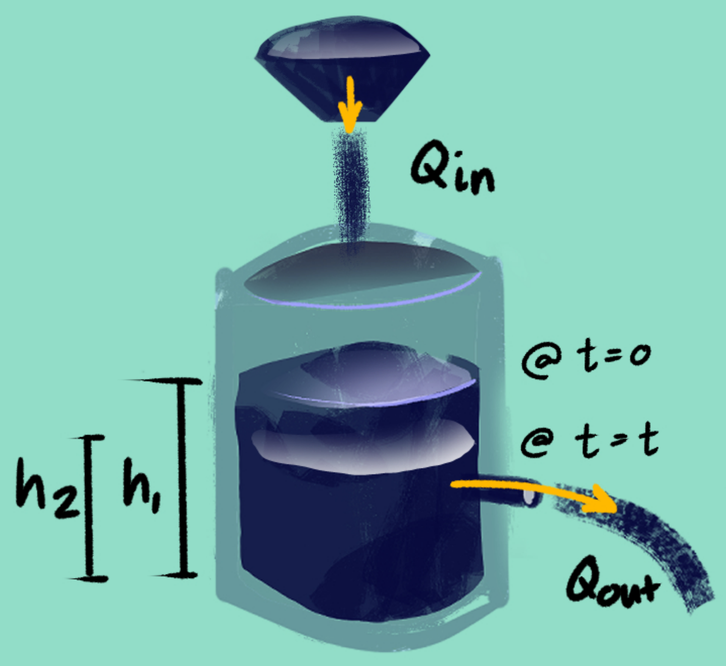
$$C_d = C_c \cdot C_v$$

C_d	COEFFICIENT OF DISCHARGE
C_c	COEFFICIENT OF CONTRACTION
C_v	COEFFICIENT OF VELOCITY

COORDINATES OF FLUID STREAMS FROM ORIFICE

$$X = 2C_v\sqrt{hy} \qquad y = \frac{x^2}{4h(C_v)^2}$$

ORIFICE UNSTEADY FLOW



CASE	CONDITION	FORMULA
1	$Q_{in} = 0$	$t = \int_{h_2}^{h_1} \frac{dV}{C_d A_o \sqrt{2gh}}$
2	$Q_{in} < Q_{out}$	$t = \int_{h_1}^{h_2} \frac{dV}{C_d A_o \sqrt{2gh} - Q_i}$
3	$Q_{in} > Q_{out}$	$t = \int_{h_1}^{h_2} \frac{dV}{Q_i - C_d A_o \sqrt{2gh}}$

WEIRS

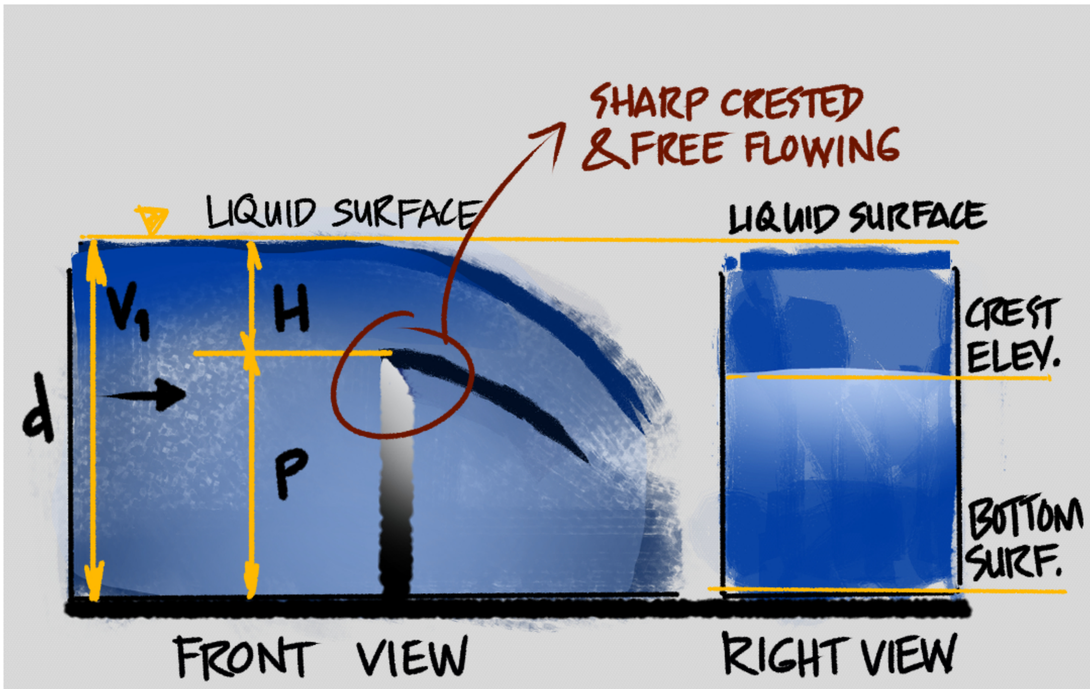
- AN OBSTRUCTION OF STREAM FLOW OVER WHICH THE WATER FLOWS

NOTCHES (MADE OUT OF METAL)

- ARE USED TO MEASURE DISCHARGE THROUGH SMALL CHANNEL, A SMALL STREAM OR TANK

WEIRS (MADE OF MASONRY STRUCTURE)

- ARE USED TO MEASURE LARGE DISCHARGE OVER CHANNEL OR RIVER.



$$t = \int_{h_1}^{h_2} \frac{dV}{Q_w}$$

WHERE:

$dV = AdH$

$Q_w = CdLH^{3/2}$ (RECTANGULAR WEIR)

$Q_w = CdH^{5/2}$ (TRIANGULAR WEIR)

☐ THEORETICAL FLOW

$$Q_T = \frac{2}{3}\sqrt{2gL}\left[\left(H + \frac{V_1^2}{2g}\right)^{3/2} - \left(\frac{V_1^2}{2g}\right)^{3/2}\right]$$

☐ ACTUAL FLOW

$$Q_a = CdL\left[\left(H + \frac{V_1^2}{2g}\right)^{3/2} - \left(\frac{V_1^2}{2g}\right)^{3/2}\right]$$

$Q_a = CLH^{3/2}$

WHEN: $\frac{V_1^2}{2g} = 0$

☐ FRANCIS FLOW

$C_f = 0.622$

$Q_a = 1.84\,LH^{3/2}$

NOTE:

$Cd = C_f \frac{2}{3}\sqrt{2g}$

C_f = CORRECTION FACTOR (≈ 0.6)

L = LENGTH OF THE CREST

W_c = WIDTH OF CHANNEL

H = HEAD OVER THE CREST

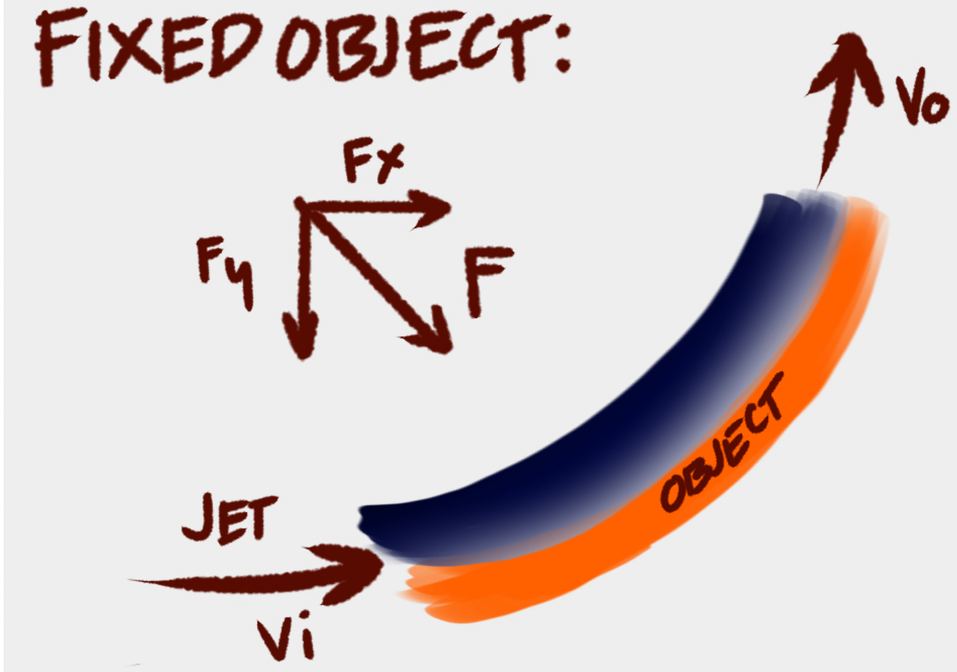
P = HEIGHT OF WEIR

V_1 = VELOCITY APPROACH

d = DEPTH OF UPSTREAM

HYDRODYNAMICS

FIXED OBJECT:



FORCE ON FIXED OBJECTS

☐ HORIZONTAL COMP.

$F_x = \frac{\gamma Q}{g}(V_{ox} - V_{ix})$

☐ VERTICAL COMP.

$F_y = \frac{\gamma Q}{g}(V_{oy} - V_{iy})$

☐ RESULTANT

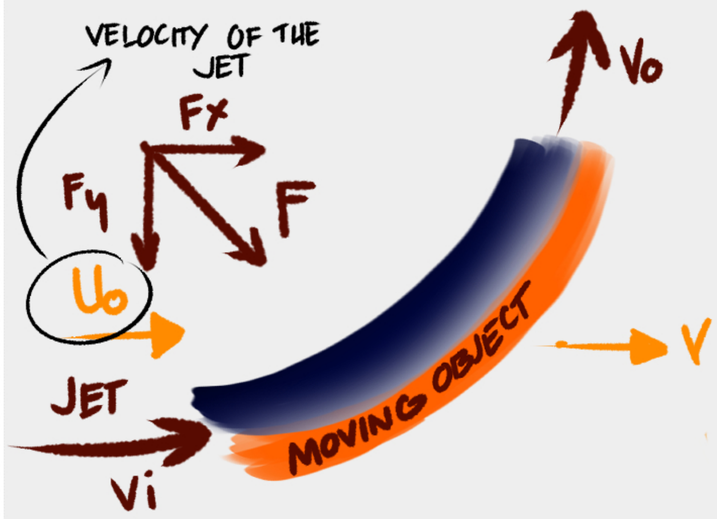
$F = \sqrt{F_x^2 + F_y^2}$

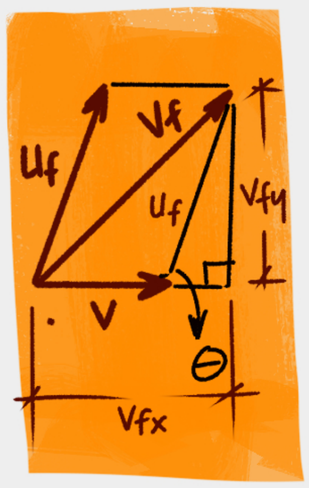
NOTE:

$Q = AV_o$

A = AREA OF THE JET

MOVING OBJECT:





FORCE ON MOVING OBJECTS

☐ HORIZONTAL COMP.

$F_x = \frac{\gamma Q'}{g}(V_{ox} - V_{ix})$

☐ VERTICAL COMP.

$F_y = \frac{\gamma Q'}{g}(V_{oy} - V_{iy})$

☐ RESULTANT

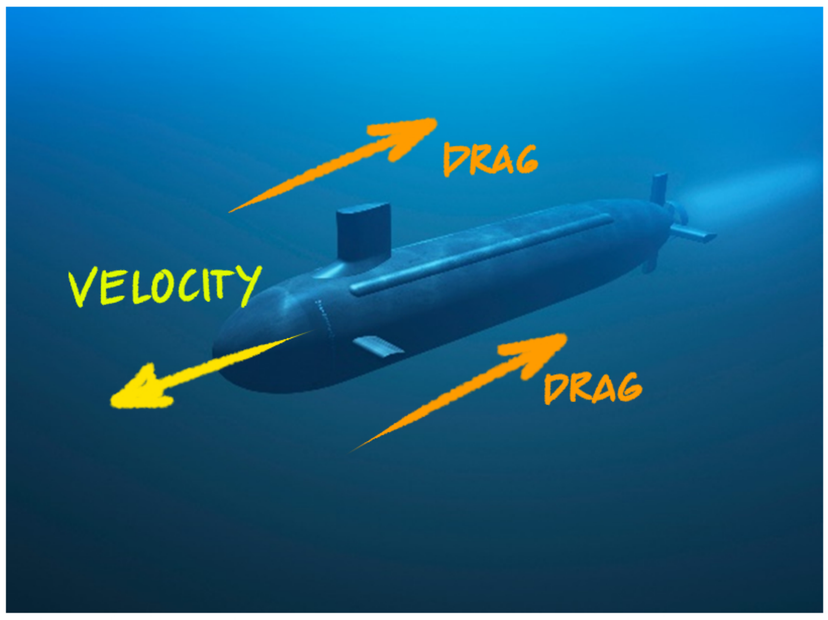
$F = \sqrt{F_x^2 + F_y^2}$

$Q' = AU_o$

WHERE:

$U_o = V_o - V$

DRAG FORCE



DRAG FORCE IS THE **RESISTANCE FORCE CAUSED BY THE MOTION OF A BODY THROUGH A FLUID**, SUCH AS WATER OR AIR. A DRAG FORCE ACTS OPPOSITE TO THE DIRECTION OF THE ONCOMING FLOW VELOCITY.

DRAG FORCE:

$$F_d = \frac{1}{2} C_d \rho A V^2$$

NOTE:

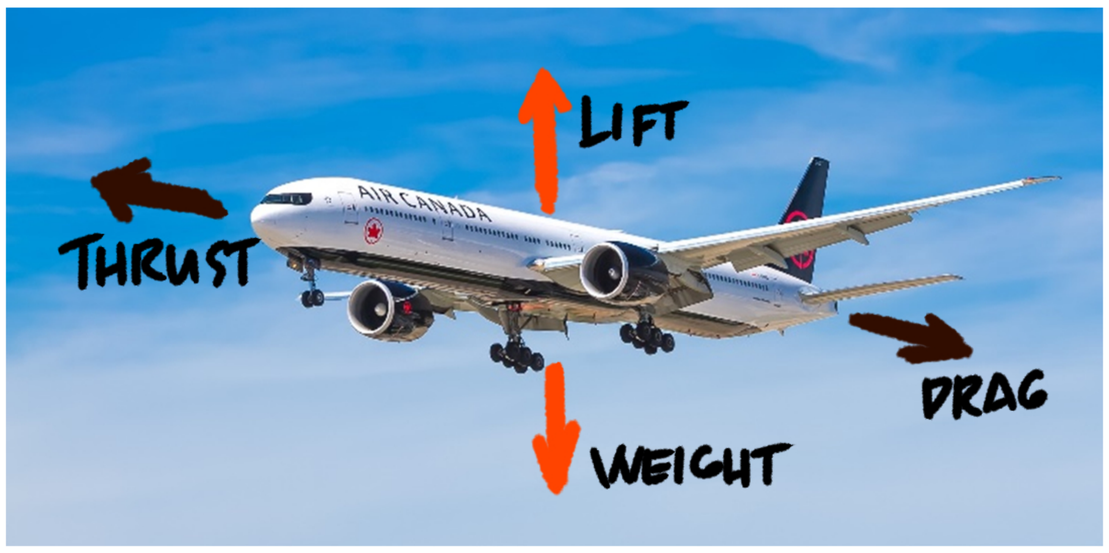
C_d = COEFFICIENT OF DRAG

A = PROJECTED AREA

AT TERMINAL, THE DRAG FORCE IS EQUAL TO = **WEIGHT VELOCITY**

$$\left(\frac{1}{2} C_d \rho A V^2 = mg\right)$$

LIFT FORCE



LIFT IS THE FORCE THAT **DIRECTLY OPPOSES THE WEIGHT OF AN AIRPLANE AND HOLDS THE AIRPLANE IN THE AIR.**

LIFT IS **GENERATED BY THE DIFFERENCE IN VELOCITY** BETWEEN THE SOLID OBJECT AND THE FLUID. THERE MUST BE MOTION BETWEEN THE OBJECT AND THE FLUID: **NO MOTION, NO LIFT**

LIFT FORCE:

$$F_L = \frac{1}{2} C_d \rho A V^2$$

NOTE:

C_L = COEFFICIENT OF PROJECTED AREA

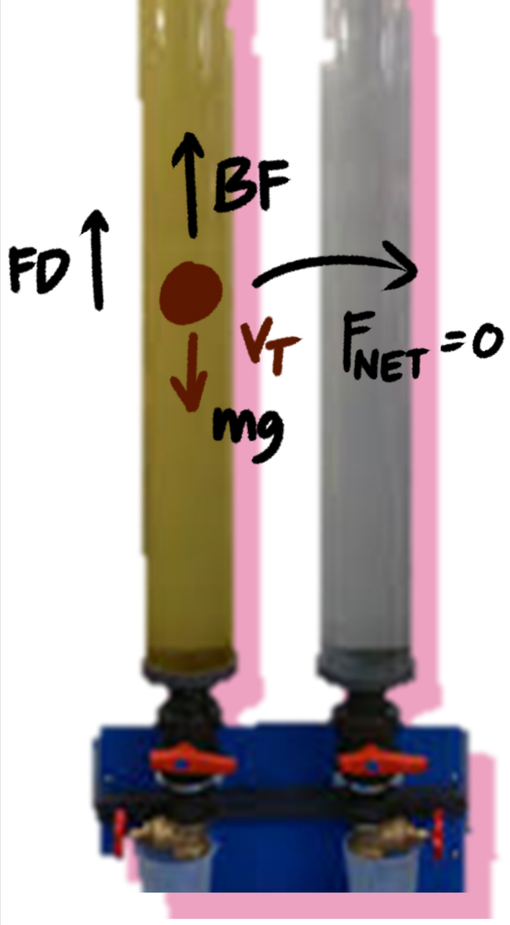
A =

COEFFICIENT OF LIFT

$$C_L = 2\pi \sin\theta$$

STOKES' LAW

- THE LAW THAT STATES THAT THE FORCE THAT RETARDS A SPHERE MOVING THROUGH A VISCOUS FLUID IS DIRECTLY PROPORTIONAL TO THE VELOCITY OF THE SPHERE, THE RADIUS OF THE SPHERE, AND THE VISCOSITY OF THE FLUID
- STOKES LAW IS THE BASIS OF THE **FALLING-SPHERE VISCOMETER**, IN WHICH THE FLUID IS STATIONARY IN A VERTICAL GLASS TUBE.



$$F_D + B_F = mg$$

$$F_D = mg - B_F$$

$$F_D = 6\pi M_d R V_T$$

$$V_T = \frac{D^2 g}{18 M_d}\left(\rho_{SPHERE} - \rho_{FLUID}\right)$$

WHERE:

F_D = FORCE

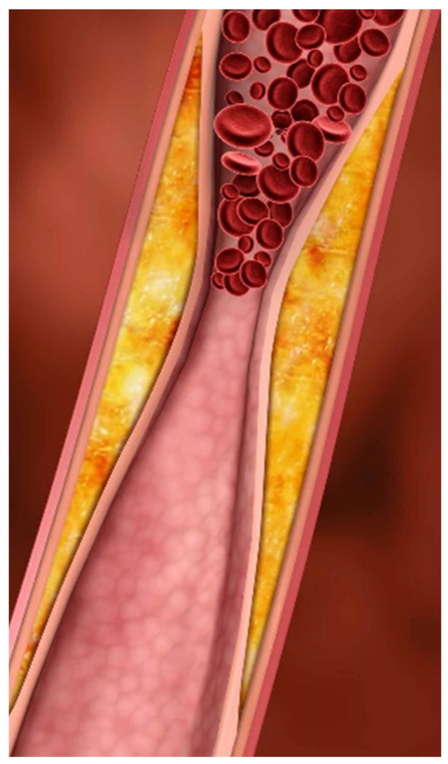
V_T = TERMINAL VELOCITY

M_d = DYNAMIC VISCOSITY

POISEUILLE'S LAW

A PHYSICAL LAW THAT GIVES THE **PRESSURE DROP** IN AN INCOMPRESSIBLE AND NEWTONIAN FLUID

$$\Delta P = \frac{8QM_dL}{\pi R^4}$$



GAS POWER CYCLES

EXTERNAL COMBUSTION ENGINE (ECE) –THE **GENERATION OF HEAT IS EFFECTED OUTSIDE THE WORK-PRODUCING UNIT**; COMBUSTOR IS DISTINCT AND SEPARATE FROM THE UNIT; TYPICAL EXAMPLE INCLUDES STEAM ENGINE.

INTERNAL-COMBUSTION ENGINE (ICE) –THE **GENERATION OF HEAT IS EFFECTED INSIDE THE WORK PRODUCING UNIT**; COMBUSTOR AND UNIT ARE THE SAME; PRODUCTS OF COMBUSTION EVENTUALLY BECOME THE WORKING FLUID.

INTERNAL COMBUSTION ENGINE

PROPULSION SYSTEM – IS A SYSTEM WHICH CHANGES THE MOMENTUM OF A DRIVEN BODY; IT COVERS SYSTEM THAT DRIVES VEHICLES AND MAJOR PIECES OF INDUSTRIAL EQUIPMENT.

HEAT ENGINES – ARE MACHINES THAT CONVERT HEAT INTO WORK OR MECHANICAL ENERGY; HEAT SUPPLIED COMES FROM THE COMBUSTION OF A CERTAIN AMOUNT OF FUEL IN OXYGEN (AIR); A WORKING FLUID ABSORBS THE HEAT SUPPLIED IN ORDER TO DRIVE THE LINKAGES THAT PRODUCE THE MECHANICAL ENERGY.

MANNER OF IGNITION

SPARK-IGNITION ENGINE (SI ENGINE)

- ACCEPTS AIR-FUEL MIXTURE UPON INTAKE; FUEL USED IS GASOLINE; IGNITION ENERGY **SUPPLIED BY SPARK PLUG.**

COMPRESSION-IGNITION ENGINE (CI ENGINE)

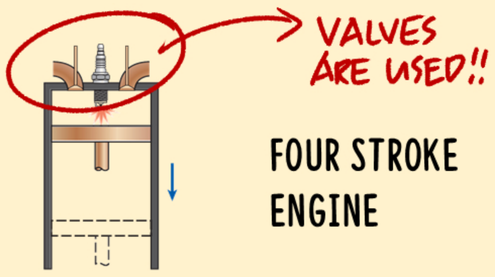
- ACCEPTS ONLY AIR UPON INTAKE; FUEL IS SPRAYED THROUGH A NOZZLE INSIDE ENGINE CYLINDER UPON REACHING ITS AUTO-IGNITION TEMPERATURE; FUEL USED IS DIESEL; IGNITION **ENERGY SUPPLIED BY HEAT OF COMPRESSION.**

TYPE OF ENGINE	FUEL USED	METHOD OF IGNITION	CYCLE
GASOLINE	GASOLINE	SPARK	0
KEROSENE	KEROSENE	SPARK	0
GAS	GASEOUS FUEL	SPARK	0
DIESEL	DIESEL	COMPRESSION	D
OIL-DIESEL	FUEL OILS	COMPRESSION	D

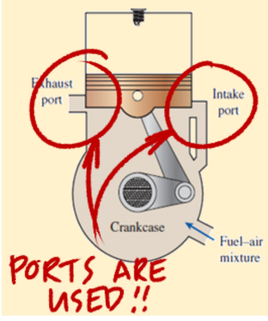
CLASSIFICATIONS ...

NUMBER OF STROKE PER CYCLE	TWO STROKE	METHOD OF STARTING	MANUAL: CRANK, ROPE, KICK
	FOUR STROKE		ELECTRIC: BATTERY
NUMBER OF CYLINDERS	SINGLE - CYLINDER		COMPRESSED AIR
	TWO - CYLINDER		USING OTHER ENGINE
	THREE - CYLINDER, AND ETC.	APPLICATION	AUTOMOTIVE
POSITION OF CYLINDERS	VERTICAL		MARINE
	HORIZONTAL		INDUSTRIAL
	INCLINE		STATIONARY POWER
ARRANGEMENT OF CYLINDERS	IN-LINE		LOCOMOTIVE
	RADIAL		AIRCRAFT
	OPPOSED CYLINDER	NUMBER OF PISTON SIDES WORKING	SINGLE-ACTING
	OPPOSED PISTON		DOUBLE-ACTING
	V-TYPE	INTAKE PRESSURE	NATURALLY ASPIRATED
METHOD OF COOLING	AIR COOLED		SUPERCHARGED
	WATER COOLED		

4 STROKE VS. 2 STROKE??



FOUR STROKE ENGINE



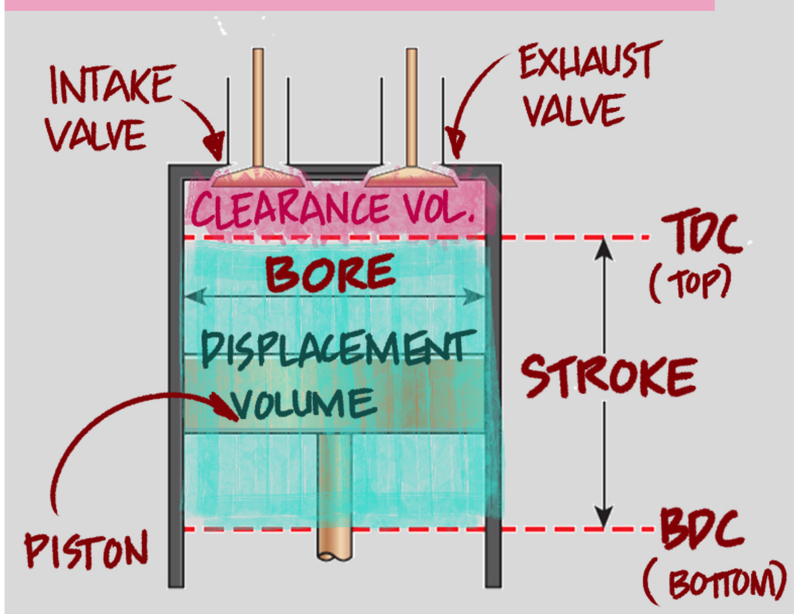
TWO STROKE ENGINE

THE TWO-STROKE ENGINES ARE GENERALLY LESS EFFICIENT THAN THEIR FOUR-STROKE COUNTERPARTS, SIMPLE AND RELATIVELY INEXPENSIVE. **HIGH POWER TO WEIGHT, AND POWER TO VOLUME RATIOS**

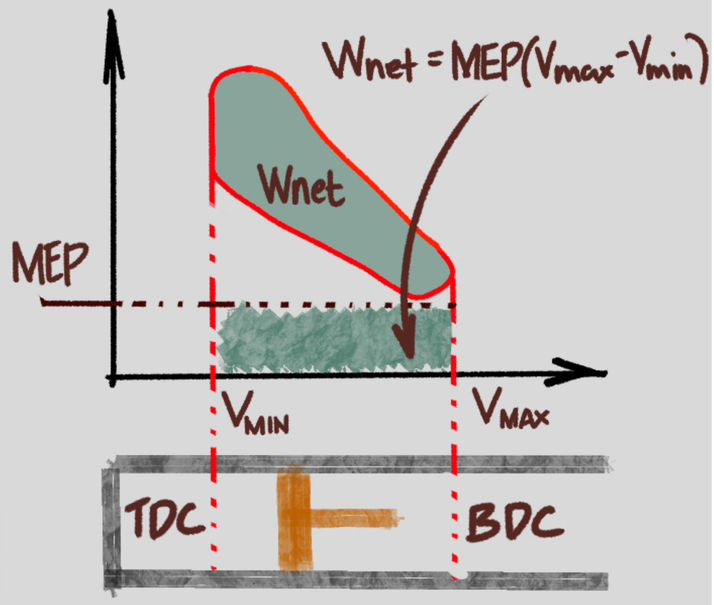
4 STROKE CYCLE
= 1 CYCLE
= 4 STROKE
= 2 REVOLUTION

2 STROKE CYCLE
= 1 CYCLE
= 2 STROKE
= 1 REVOLUTION

NOMENCLATURE OF RECIPROCATING ENGINE



1.4 = COLD AIR STD. EFFICIENCY
1.3 = HOT AIR STD. EFFICIENCY



AIR-STANDARD ASSUMPTIONS

COLD-AIR STD. CYCLE

- WHEN THE WORKING FLUID IS CONSIDERED TO BE AIR WITH CONSTANT SPECIFIC HEATS AT ROOM TEMP.

HOT-AIR STD. CYCLE

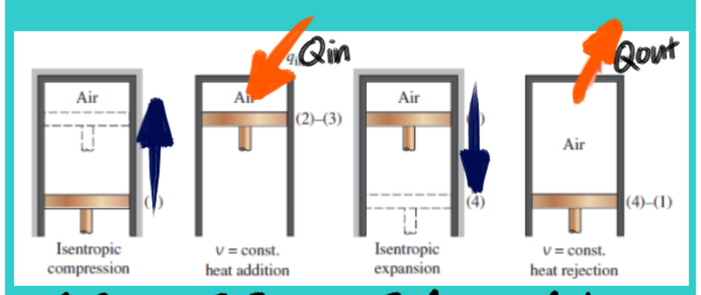
- A CYCLE FOR WHICH THE AIR-STANDARD ASSUMPTIONS ARE APPLICABLE.

NOTE!!!
OCTANE NUMBER: IGNITION RATING OF GASOLINE
CETANE NUMBER: IGNITION RATING OF DIESEL

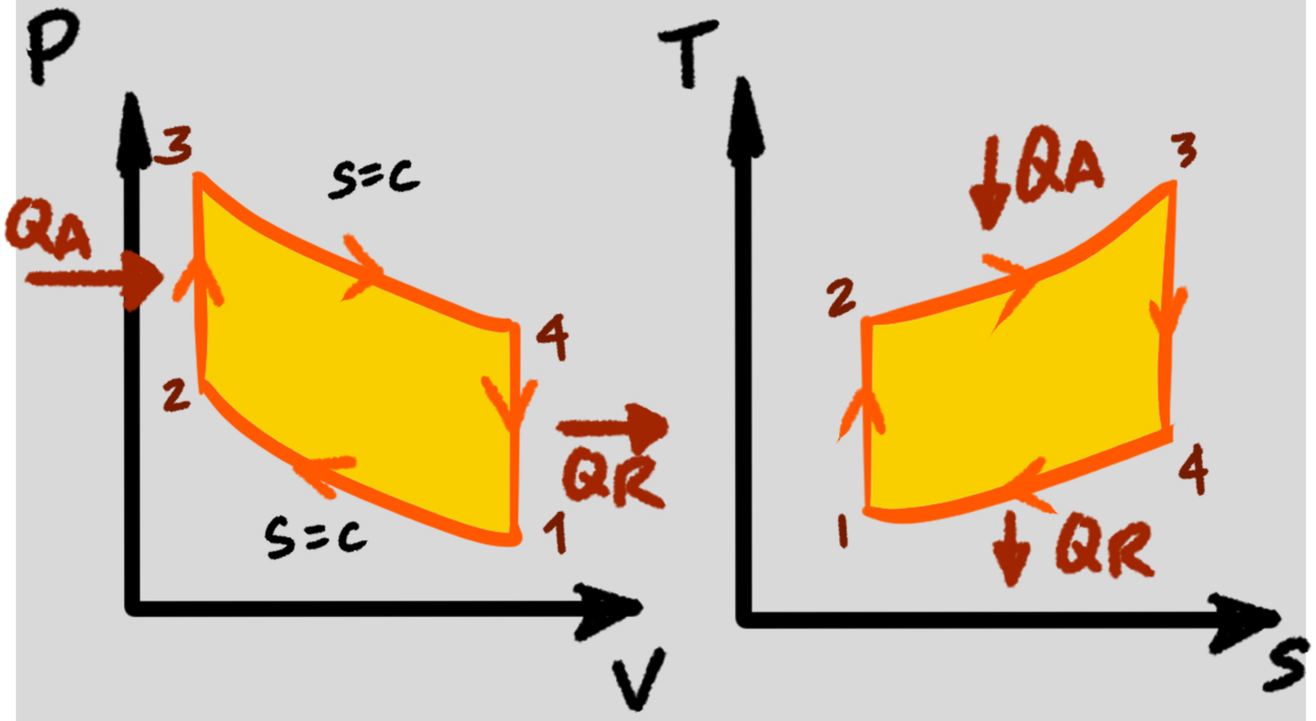
OTTO CYCLE: IDEAL CYCLE FOR SPARK IGNITION ENGINE GASOLINE ENGINE

IT IS NAMED AFTER **NIKOLAUS A. OTTO**, WHO BUILT A SUCCESSFUL FOUR-STROKE ENGINE IN **1876** IN GERMANY.

PROCESSES INVOLVED



1-2	ISENTROPIC COMPRESSION
2-3	CONSTANT VOLUME HEAT ADDITION
3-4	ISENTROPIC EXPANSION
4-1	CONSTANT VOLUME HEAT REJECTION



FORMULA:

$V_D = V_1 - V_2$

$V_c = V_2$

$V_c = cV_D$

$r_k = \frac{c+1}{c} = \frac{V_1}{V_2}$

☑ FOR ISENTROPIC PROCESS

$r_k = \frac{V_1}{V_2} = \left(\frac{P_2}{P_1}\right)^{1/k} = \left(\frac{T_2}{T_1}\right)^{\frac{1}{k-1}}$

☑ HEAT ADDITION
$Q_A = mC_v(T_3 - T_2)$

☑ HEAT REJECTION
$Q_R = mC_v(T_4 - T_1)$

$\text{WORK NET} = Q_A - Q_R = P_{MEP} V_D$

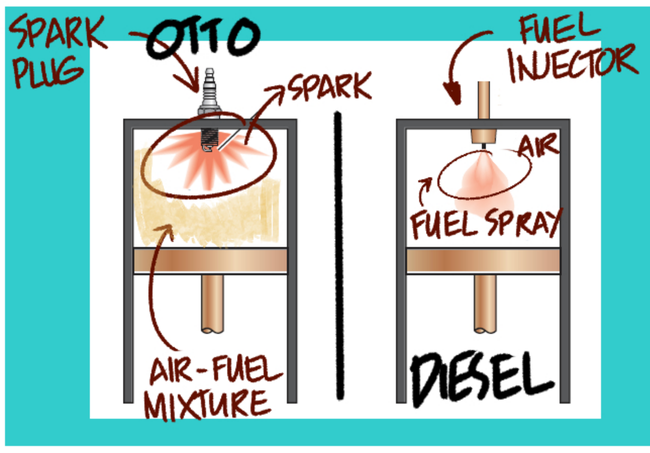
☑ CYCLE EFFICIENCY

$e = 1 - \frac{1}{r_k^{k-1}}$

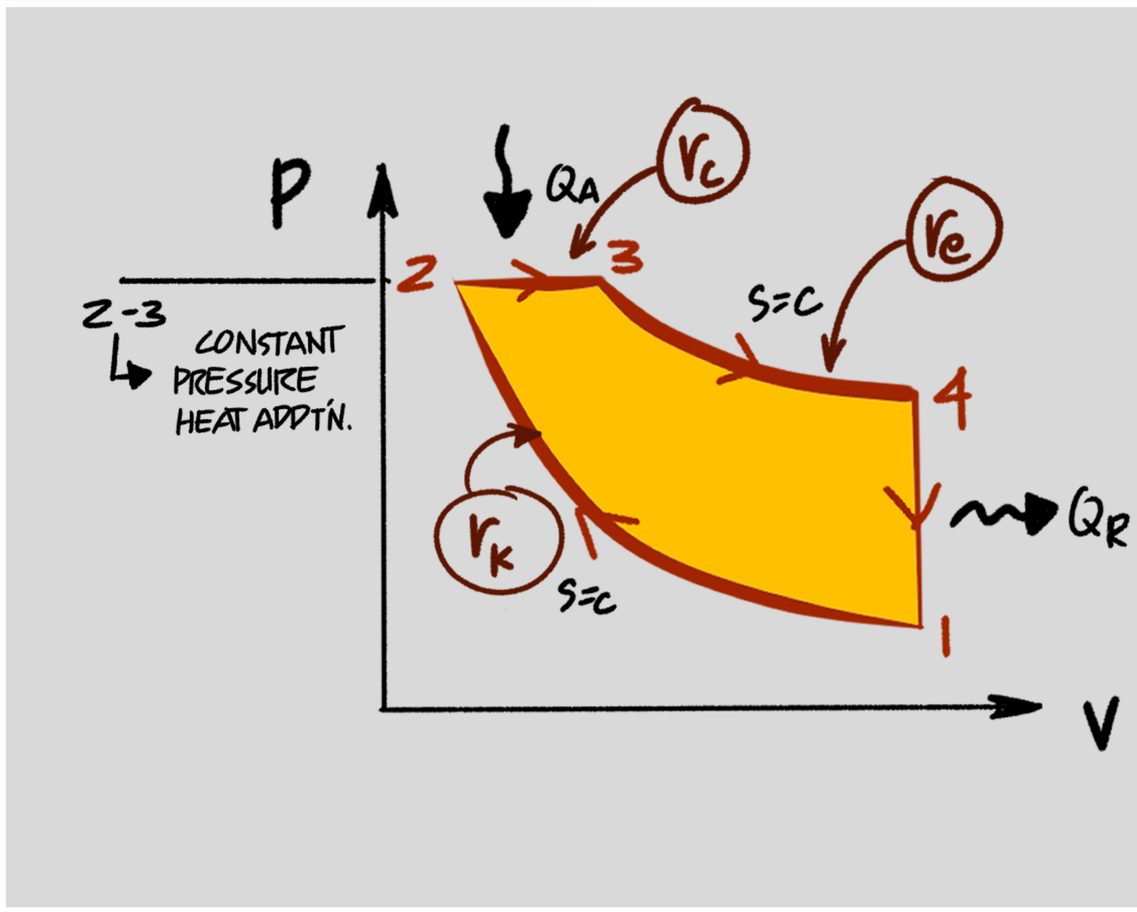
DIESEL CYCLE: IDEAL CYCLE FOR COMPRESSION IGNITION ENGINE

DIESEL ENGINE

FIRST PROPOSED BY **RUDOLPH DIESEL** IN THE **1980**S



1-2	ISENTROPIC COMPRESSION
2-3	CONSTANT PRESSURE HEAT ADDITION
3-4	ISENTROPIC EXPANSION
4-1	CONSTANT VOLUME HEAT REJECTION



RATIOS:

COMPRESSION	r_K	V_2 / V_1
CUT-OFF	r_c	V_3 / V_2
EXPANSION	r_e	V_4 / V_3

ALSO; $r_K = r_c \cdot r_e$

$$\text{cut-off RATIO} = \frac{c+s}{s}$$

WHERE:
C = % CLEARANCE
S = % STROKE

☑ HEAT ADDITION

$$Q_A = mc_p(T_3 - T_2)$$

SINCE P=C

☑ HEAT REJECTION

$$Q_R = mc_v(T_4 - T_1)$$

☑ CYCLE EFFICIENCY

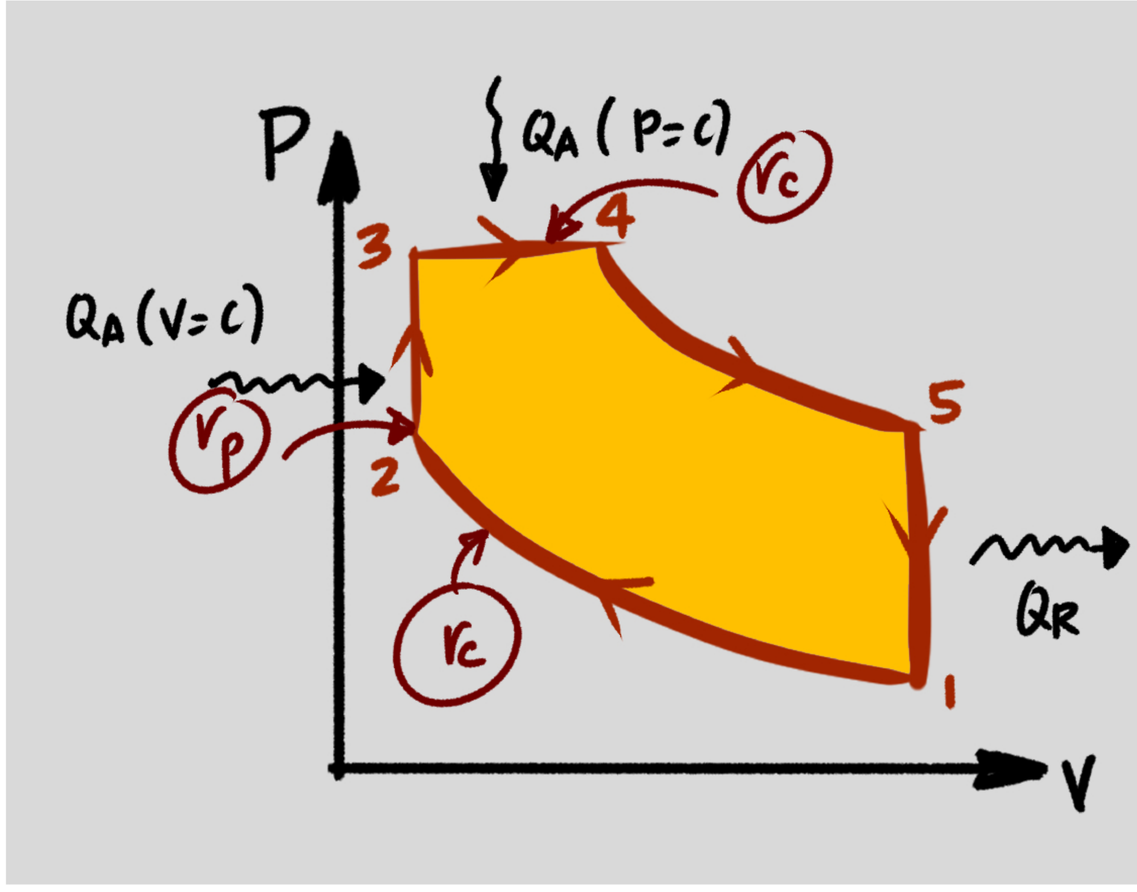
$$e = 1 - \frac{1}{r_k^{k-1}}\left[\frac{r_c^{k-1}}{k(r_c - 1)}\right]$$

DUAL CYCLE: LIMITED COMBUSTION CYCLE

MIXED CYCLE | SEILIGER CYCLE | SABATHE CYCLE

DUAL CYCLE IS A MORE REALISTIC MODEL THAN DIESEL CYCLE FOR REPRESENTING **MODERN, HIGH-SPEED COMPRESSION IGNITION ENGINES.**

2-3	CONSTANT VOLUME HEAT ADDITION
3-4	CONSTANT PRESSURE HEAT ADDITION



$$r_p = \frac{P_3}{P_2} = \frac{T_3}{T_2}$$

$$r_c = \frac{V_4}{V_3} = \frac{T_4}{T_3}$$

ALSO;

$$T_5 = T_1 r_p r_c^{\,k}$$

☑ HEAT ADDITION

$$Q_A = mc_v(T_3 - T_2) + mc_p(T_4 - T_3)$$

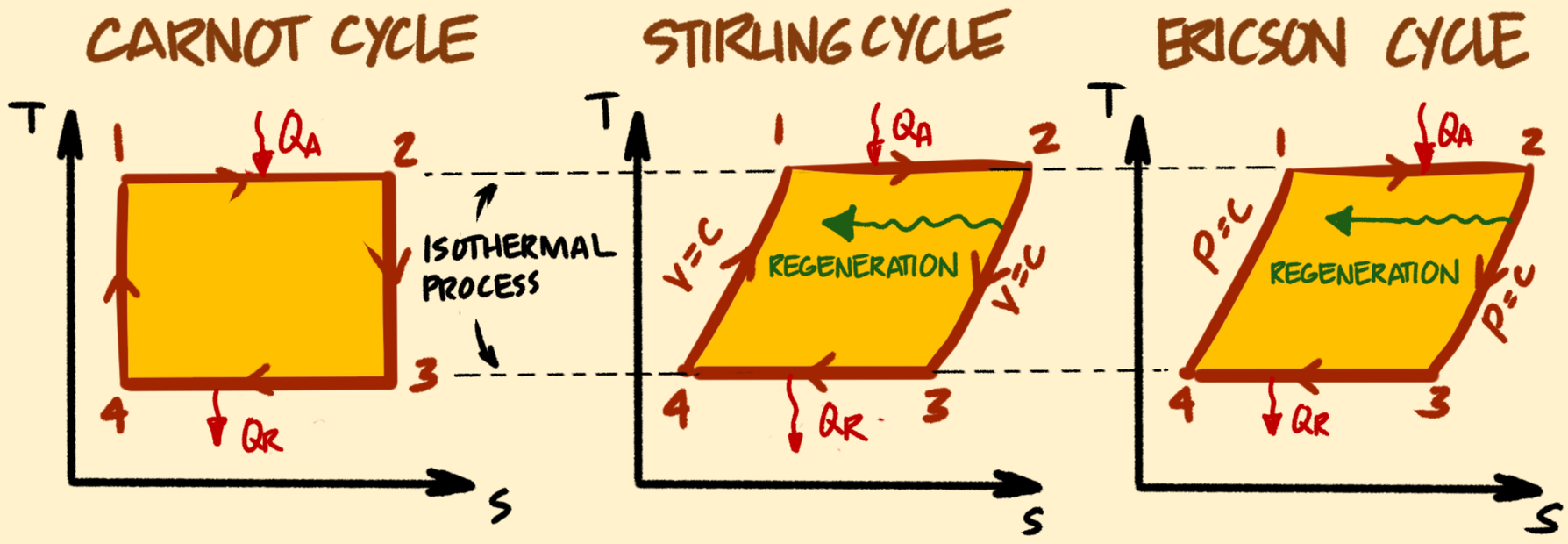
☑ HEAT REJECTION

$$Q_R = mc_v(T_5 - T_1)$$

SUMMARY OF EFFICIENCIES

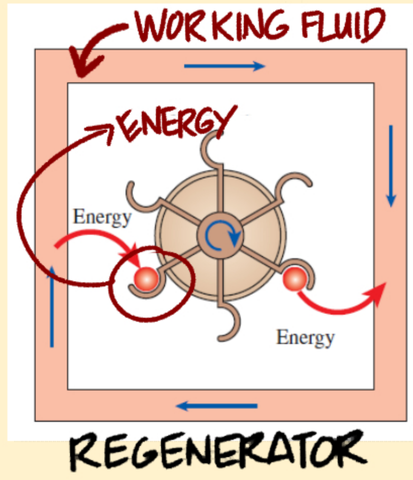
	MULTIPLY	FACTOR
OTTO	$e = 1 - \frac{1}{r_k^{k-1}}$	1
DIESEL	$e = 1 - \frac{1}{r_k^{k-1}}$	$\left[\frac{r_c^{k-1}}{k(r_c - 1)}\right]$
DUAL	$e = 1 - \frac{1}{r_k^{k-1}}$	$\left[\frac{r_p r_c^{\,k} - 1}{(r_p - 1) + r_p k(r_c - 1)}\right]$

OTHER CYCLES THAT PERFORM 2 ISOTHERMAL HEATING



- SAME EFFICIENCY WITH CARNOT IF SAME TEMPERATURE LIMITS!!!!
- EXTERNAL COMBUSTION ENGINE
- HYDROGEN AND HELIUM ARE TWO GASES COMMONLY EMPLOYED IN BOTH CYCLES

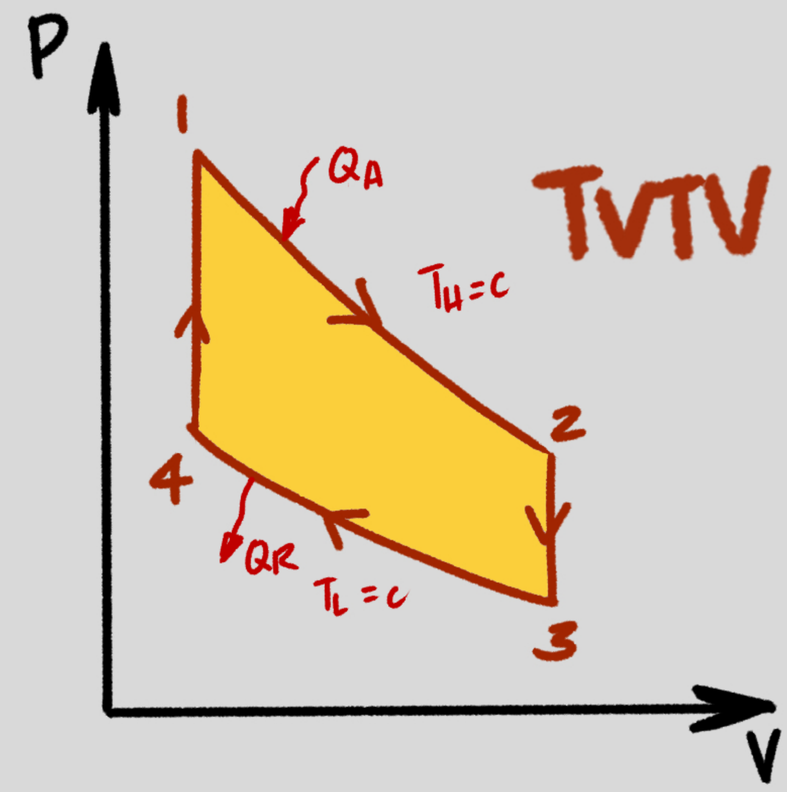
THEY DIFFER FROM THE CARNOT CYCLE IN THAT THE TWO ISENTROPIC PROCESSES ARE REPLACED
TWO CONSTANT-VOLUME REGENERATION PROCESSES IN THE STIRLING CYCLE
TWO CONSTANT-PRESSURE REGENERATION PROCESSES IN THE ERICSSON CYCLE.
BOTH CYCLES UTILIZE REGENERATION, A PROCESS DURING WHICH HEAT IS TRANSFERRED TO A THERMAL ENERGY STORAGE DEVICE (CALLED A **REGENERATOR**) DURING ONE PART OF THE CYCLE AND IS TRANSFERRED BACK TO THE WORKING FLUID DURING ANOTHER PART OF THE CYCLE.



BORROWS ENERGY DURING ONE PART OF CYCLE & PAY BACK (W/O INTEREST) IN THE NEXT CYCLE.

STIRLING CYCLE (VOLUME)

- NOT USED TO MODEL ACTUAL ENGINES
- ILLUSTRATED WITH THE USE OF REGENERATOR, ABSORBS HEAT & TRANSFER IT TO WORKING FLUID.



- HEAT STORED - CONSTANT TEMP. EXPANSION
- HEAT REUSED - CONSTANT TEMP. COMPRESSION

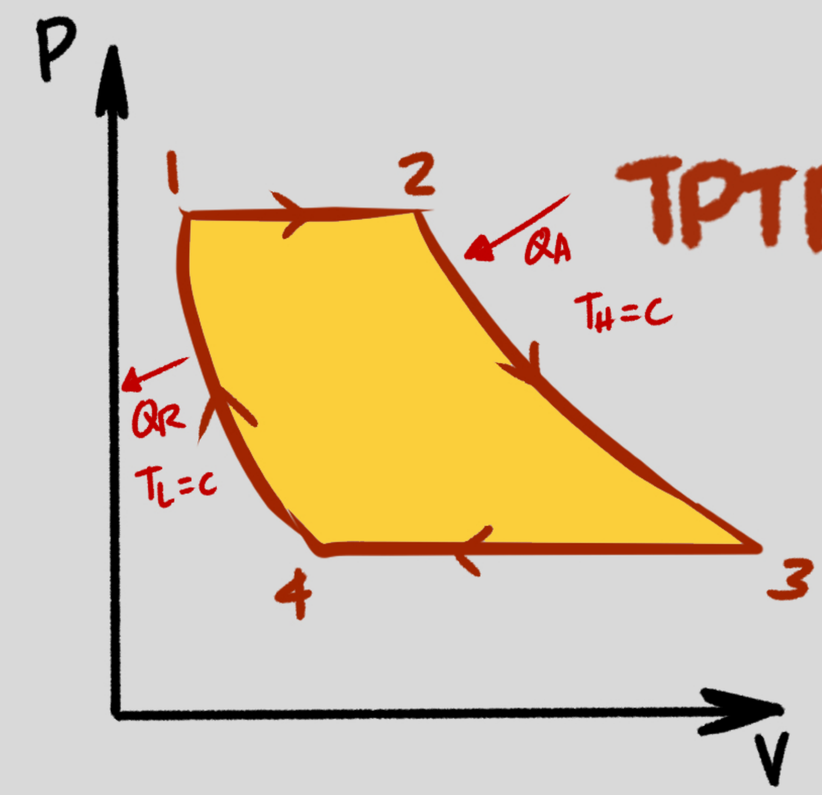
$$e = \frac{W_{net}}{Q_A} = \frac{Q_A - Q_R}{Q_A}$$

$$e = \frac{T_H - T_L}{T_H}$$

(SAME AS CARNOT e)

ERICSON CYCLE (PRESSURE)

- NOT USED TO MODEL ACTUAL ENGINES
- ILLUSTRATED WITH THE USE OF REGENERATOR, ABSORBS HEAT & TRANSFER IT TO WORKING FLUID.



- HEAT STORED - CONSTANT TEMP. EXPANSION
- HEAT REUSED - CONSTANT TEMP. COMPRESSION

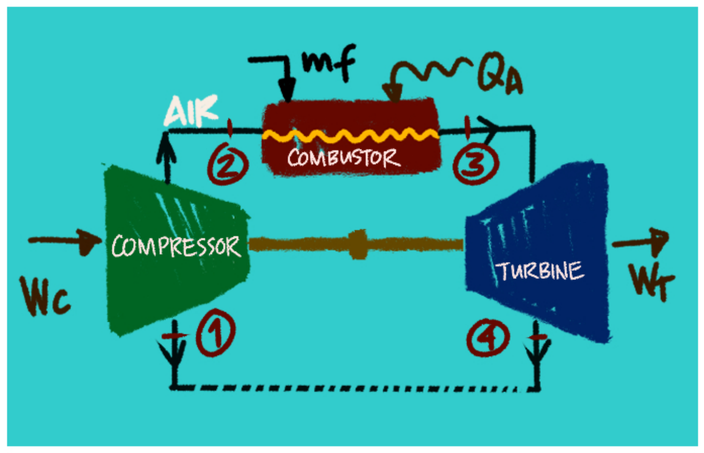
$$e = \frac{W_{net}}{Q_A} = \frac{Q_A - Q_R}{Q_A}$$

$$e = \frac{T_H - T_L}{T_H}$$

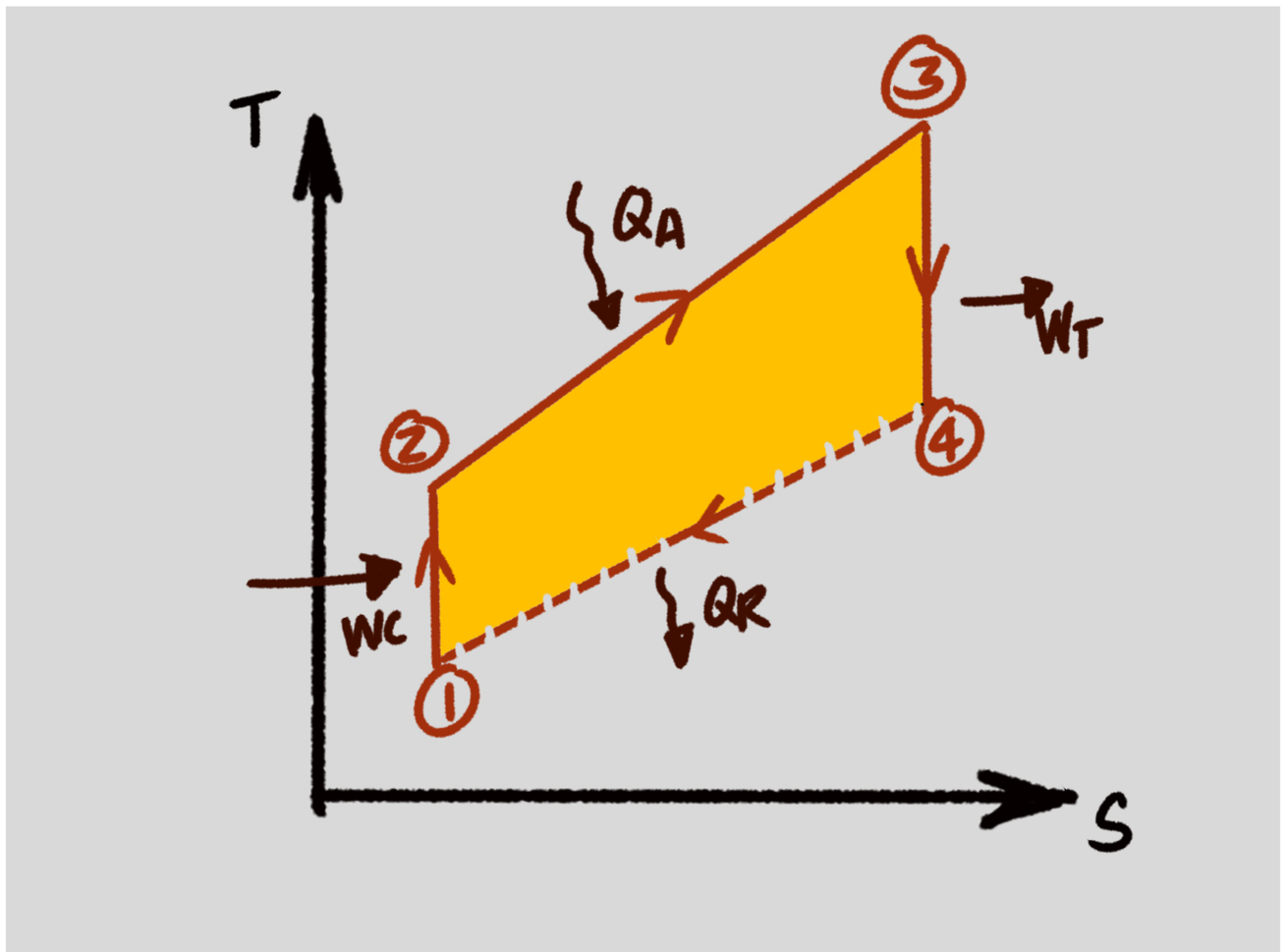
(SAME AS CARNOT e)

BRAYTON CYCLE

THE BRAYTON CYCLE WAS FIRST PROPOSED BY **GEORGE BRAYTON** FOR USE IN THERE RECIPROCATING OIL-BURNING ENGINE THAT HE DEVELOPED AROUND **1870.**



1-2	ISENTROPIC COMPRESSION
2-3	CONSTANT PRESSURE HEAT ADDITION
3-4	ISENTROPIC EXPANSION
4-1	CONSTANT PRESSURE REJECTION



FOR ISENTROPIC PROCESS:

$$(r_p)^{\frac{k-1}{k}} = \frac{T_2}{T_1}$$

$$W_C = mc_p\Delta T_{1-2}$$

$$W_T = mc_p\Delta T_{3-4}$$

$$Q_A = mc_p\Delta T_{2-3}$$

☑ CYCLE EFFICIENCY

$$e = 1 - \frac{1}{r_p^{\frac{k-1}{k}}}$$

☑ BACK WORK RATIO

$$BW_R = \frac{W_C}{W_T}$$

FOR MAXIMUM THEO. NETWORK:

$$T_2 = \sqrt{T_1 T_3}$$

$$T_2 = T_4$$

POWER CYCLES

(DBER|SC|LOAD)

D	DIESEL	SPSV	RUDOLF CHRISTIAN KARL **DIESEL**
B	BRAYTON	SPSP	GEORGE BAILEY **BRAYTON**
E	ERICSON	PTPT	JOHN **ERICSON**
R	RANKINE	SPSP	WILLIAM JOHN MACQUORN **RANKINE**
S	STIRLING	TVTV	NICOLAS LEONARD SADI **CARNOT**
C	CARNOT	STST	ROBERT **STIRLING**
L	*LENOIR*	*VSP*	*JEAN JOSEPH ETIENNE **LENOIR***
O	OTTO	SVSV	NIKOLAUS AUGUST **OTTO**
A	*ATKINSON*	*SVPSVP*	*JAMES **ATKINSON***
D	DUAL	SVPSV	GUSTAV TRINKLER

FUELS AND COMBUSTION

FUEL – SUBSTANCE WHICH UPON COMBUSTION **RELEASES HEAT**
COMBUSTION –**UNION WITH OXYGEN** WHOSE EXOTHERMIC HEAT OF REACTION IS GREAT AND WHOSE RATE OF REACTION IS FAST THAT USEFUL QUANTITIES OF HEAT ARE LIBERATED.

TYPES OF FUELS

SOLID
- COAL, COKE, PEAT, BRIQUETTES, WOOD, CHARCOAL, AND WASTE PRODUCTS

LIQUID
- PETROLEUM AND ITS DERIVATIVES, SYNTHETIC LIQUID FUELS, SHALE OIL, COAL BY-PRODUCTS, AND ALCOHOLS.

GASEOUS
- NATURAL GAS, MANUFACTURED AND INDUSTRIAL BY-PRODUCT GASES, AND THE PROPANE AND BUTANE OR, LIQUEFIED PETROLEUM (LP) GASES.

ATOMIC FUELS
- NATURAL URANIUM, THORIUM ..

SOLID FUELS: COAL CLASSIFICATION

1. CLASSIFICATION BY RANK
- DEGREE OF METAMORPHISM, OR PROGRESSIVE ALTERATION, IN THE NATURAL SERIES FROM LIGNITE TO ANTHRACITE
- PROBABLY THE **MOST UNIVERSALLY APPLICABLE METHOD OF CLASSIFICATION** IN WHICH COALS ARE ARRANGED ACCORDING TO **FIXED CARBON CONTENT AND CALORIFIC VALUE**, IN BTU, CALCULATED ON THE MINERAL-MATTER-FREE BASIS.

I	ANTHRACITE
II	BITUMINOUS
III	SUB-BITUMINOUS
IV	LIGNITE

2. CLASSIFICATION BY GRADE
- QUALITY DETERMINED BY **SIZE DESIGNATION, CALORIFIC VALUE, ASH, ASH-SOFTENING TEMPERATURE, AND SULFUR.**

3. CLASSIFICATION BY TYPE OR VARIETY
- DETERMINED BY NATURE OF THE **ORIGINAL PLANT MATERIAL** AND SUBSEQUENT THEREOF.

THREE VARIETIES OF COAL IN THE HIGH-VOLATILE C BITUMINOUS GROUP:
AGGLOMERATING AND NON-WEATHERING
AGGLOMERATING AND WEATHERING
NON-AGGLOMERATING AND NON-WEATHERING

BURNERS FOR PULVERIZED COAL

1. VERTICAL FIRING
- WITH ALL **THE SECONDARY AIR ADMITTED AROUND THE BURNER NOZZLE** SO THAT IT MIXES QUICKLY WITH COAL PRIMARY AIR MIXTURE FROM THE BURNER NOZZLE.

2. IMPACT FIRING
- A FORM OF VERTICAL FIRING, **CONSISTS OF BURNERS LOCATED IN AN ARCH LOW IN THE FURNACE OR IN THE SIDE WALLS AND DIRECTED TOWARD THE FURNACE DOOR**, WITH HIGH VELOCITIES OF BOTH PRIMARY AND SECONDARY AIR. THIS TYPE OF FIRING IS USED EXCLUSIVELY IN WET-BOTTOM OR SLAGGING TYPE.

3. HORIZONTAL FIRING
- **EMPLOYS A TURBULENT BURNER**, WHICH CONSISTS OF A CIRCULAR NOZZLE WITHIN A HOUSING PROVIDED WITH ADJUSTABLE VALVES, THE UNIT BEING LOCATED IN THE FRONT OR REAR WALL.

4. CORNER OR TANGENTIAL FIRING
- IS CHARACTERIZED BY BURNERS LOCATED IN EACH **CORNER OF THE FURNACE AND DIRECTED TANGENT TO A HORIZONTAL**, IMAGINARY CIRCLE IN THE MIDDLE OF THE FURNACE, THEREBY MAKING THE FURNACE THE BURNER IN EFFECT, SINCE TURBULENCE AND INTENSIVE MIXING OCCUR WHERE THE STREAMS MET.

OTHER SOLID FUELS

COKE

IS THE SOLID, INFUSIBLE, CELLULAR RESIDUE LEFT **AFTER FUSIBLE BITUMINOUS COALS ARE HEATED**, IN THE ABSENCE OF AIR, ABOVE TEMPERATURES AT WHICH ACTIVE THERMAL DECOMPOSITION OF THE COAL OCCURS.

- **PITCH COKE OR PETROLEUM COKE** – ARE OBTAINED BY SIMILAR HEATING OF COAL-TAR PITCH AND PETROLEUM RESIDUES.
- **HIGH TEMPERATURE COKE** – IS MADE FROM COAL AT TEMPERATURE RANGING FROM **815** C TO **1093** C.
- **LOW TEMPERATURE COKE** – IS FORMED AT TEMPERATURES BELOW **704** C. **THE RESIDUE, IF MADE FROM A NON-COOKING COAL, IS KNOWN AS CHAR .**

WOOD FUEL

MAY COME TO THE BOILER PLANT IN THE FORM OF **CORDWOOD, SLABS, EDGING, BARK, SAWDUST, OR SHAVINGS**. THE MAJOR VARIABLE IN WOOD IS MOISTURE CONTENT.

- AIR DRIED WOOD SELDOM CONTAINS LESS THAN **12**% WATER
- KILN DRIED WOOD CONTAINS **1** TO **7** %.

GENERAL METHODS OF BURNING WOOD FUELS:

- MOVING BED / INCLINED GRATE
- IN SUSPENSION (SPREADER STOKERS)
- PILES ON FLAT GRATES

CHARCOAL

IS PRODUCED BY PARTIAL COMBUSTION OF WOOD AT ABOUT **400** C AND WITH LIMITED AIR.

TYPES:

- HARDWOOD CHARCOAL
- SOFTWOOD CHARCOAL

STRAW, PAPER, AND MISCELLANEOUS FUELS

LIQUID FUELS:

IS DEFINED AS ANY **LIQUID OR LIQUEFIABLE PETROLEUM PRODUCTS** BURNED FOR THE GENERATION OF HEAT IN A FURNACE OF FIREBOX, OF THE GENERATION OF POWER IN AN ENGINE, EXCLUSIVE OF OILS WITH A FLASH POINT BELOW **37.7** C.

COMMERCIAL FUEL OIL SPECIFICATIONS

GRADE	SPECIFICATION
1	A DISTILLATE OIL INTENDED FOR **VAPORIZING POT-TYPE BURNERS** AND OTHER BURNERS REQUIRING THIS GRADE OF FUEL.
2	A DISTILLATE OIL FOR **GENERAL PURPOSE DOMESTIC HEATING** IN BURNERS NOT REQUIRING NO. **1** FUEL OIL.
4	AN OIL FOR **BURNER INSTALLATION NOT EQUIPPED WITH PRE-HEATING FACILITIES**.
5	A RESIDUAL TYPE OIL **FOR BURNER INSTALLATION EQUIPPED WITH PRE-HEATING FACILITIES**.
6	AN OIL FOR BURNERS EQUIPPED WITH PRE-HEATERS PERMITTING **A HIGH-VISCOSITY FUEL**.

FOUR CLASSES OF FUEL OILS IN COMMON USES

RESIDUAL OILS	WHICH ARE TOPPED CRUDE PETROLEUM'S OR VISCOUS RESIDUUM OBTAINED IN REFINERY OPERATIONS
DISTILLATE FUEL OILS	WHICH ARE DISTILLATES DERIVED DIRECTLY OR INDIRECTLY FROM CRUDE PETROLEUM
CRUDE PETROLEUM AND WEATHERED CRUDE PETROLEUM	RELATIVELY LOW COMMERCIAL VALUE
BLENDED FUELS	WHICH ARE MIXTURE OF TWO OR MORE OF THE PRECEDING CLASSES

COAL TAR / TAR OIL

A PRODUCT OF THE DESTRUCTIVE DISTILLATION OF BITUMINOUS COAL CARRIED OUT AT HIGH TEMPERATURE.

GASOLINE

IS DEFINED AS A **REFINED PETROLEUM NAPHTHA** WHICH BY ITS COMPOSITION IS SUITABLE FOR USE AS A **CARBURETANT** IN INTERNAL COMBUSTION ENGINES.

MOTOR GASOLINE – IS A MIXTURE OF HYDROCARBONS DISTILLING IN THE RANGE OF **37.7**C TO **204.4** C BY THE STANDARD METHOD OF
TEST.

LPG

- **LIQUEFIED PETROLEUM GASES (LPG)** – ARE MIXTURES OF HYDROCARBONS LIQUEFIED UNDER PRESSURE FOR TRANSPORTATION AND STORAGE.
- GENERALLY COMPOSED OF **ETHYLENE, PROPANE, PROPYLENE, BUTANE, ISOBUTENE, AND BUTYLENES.**
- COMMERCIALLY, THEY ARE **CLASSED AS PROPANE, PROPANE-BUTANE MIXTURES, AND BUTANE**.
- THEY ARE ODORLESS, COLORLESS, AND NON-TOXIC.

KEROSENE

IS DEFINED AS A **PETROLEUM DISTILLATE** HAVING A FLASH POINT NOT BELOW **22.8** C AS DETERMINED BY THE ABEL TESTER AND SUITABLE AS AN **ILLUMINANT WHEN BURNED IN A WICK LAMP**.

ALCOHOLS

- **ETHYL ALCOHOL** (ETHANOL), SOMETIMES CALLED **GRAIN ALCOHOL**, IS CONSIDERED **AS FUEL FOR INTERNAL COMBUSTION ENGINE**
- OTHER ALCOHOLS USED AS FUEL ARE **METHANOL (METHYL ALCHOHOL) AND ISOPROPANOL (ISOPROPYL ALCOHOL)**

DIESEL FUEL OILS

- REFINERS GRADE FUELS CLASSIFIED ACCORDING TO METHODS OF PRODUCTION.

DISTILLATE FUELS	ARE PRODUCED BY DISTILLATION OF CRUDES
RESIDUAL FUELS	ARE THOSE LEFT AFTER THE DISTILLATION PROCESS
BLENDED FUELS	ARE MIXTURES OF STRAIGHT DISTILLATE FUELS WITH CRACKED FUEL STOCKS

COMMON HYDROCARBONS

CH_4	METHANE	C_6H_{14}	HEXANE
C_2H_6	ETHANE	C_7H_{16}	HEPTANE
C_3H_8	PROPANE	C_8H_{18}	OCTANE
C_4H_{10}	BUTANE	$C_{10}H_{22}$	DECANE
C_5H_{12}	PENTANE	C_2H_2	ACETYLENE
		$C_{16}H_{32}$	DIESEL

NOTE: ↗ PARAFFINS

- MOST HYDROCARBON FOLLOW THE FORM:

C_nH_{2n+2}

- FOR ALCOHOLS: +O if -ol FAMILY

e.g. Ethanol - C_2H_6O

- n (1-26)
- m (2-54)

GASEOUS FUELS:

ARE **COMMONLY USED IN INDUSTRY**, WHETHER DISTRIBUTED BY PUBLIC UTILITIES OR PRODUCED IN ISOLATED PLANTS, ARE **COMPOSED OF ONE OR MORE SIMPLE GASES IN VARYING PROPORTIONS.**

LUBRICANTING OILS

CRUDE OILS

- ARE FREQUENTLY DESCRIBED AS "PARAFFINIC", "NAPTHTHENIC", OR "MIXED BASED" ACCORDING TO THE PHYSICAL CHARACTERISTICS OF THE CRUDE.

TWO BROAD TYPES OF OIL

A. "STRAIGHT" OILS

— ARE PRODUCED ENTIRELY FROM THE CRUDES CHOSEN THROUGH ELIMINATION OF UNDESIRED CONSTITUENTS BY SUITABLE REFINING PROCESSES.

B. "ADDITIVE" OILS

— ARE PRODUCED BY ADDING TO STRAIGHT MINERAL OILS CERTAIN OIL-SOLUBLE COMPOUNDS THAT ENHANCE THE LUBRICATING OIL PROPERTIES FOR USE IN A DIESEL ENGINE.

SAE THREE TYPES OF LUBRICATING OILS

REGULAR TYPE	SUITABLE FOR MODERATE OPERATING CONDITIONS.
PREMIUM TYPE	HAVING OXIDATION STABILITY AND BEARING CORROSION PREVENTIVE PROPERTIES MAKING IT GENERALLY
HEAVY DUTY TYPE	HAS OXIDATION STABILITY, BEING CORROSION-PREVENTIVE PROPERTIES, AND DETERGENT-DISPERSANT

ADDITIONAL INFORMATION!!!

CRACKED STOCKS — ARE RESIDUAL OF FUELS WHICH HAVE BEEN **TREATED THERMALLY OR CATALYTICALLY TO OBTAIN YIELDS OF LIGHTERGRADE FUELS OR GASOLINE.**

LIGHTEST GRADE DISTILLATES — CLASSED AS KEROSENE OR NO. **1** FUEL OIL, MAY HAVE AN INITIAL BOILING POINT OF **176.6** C AND END POINT OF **260** C.

HEAVIEST GRADES OF DISTILLATES — CLASSED AS NO. **3** OR **4** FUEL OIL, MAY HAVE AN INITIAL BOILING POINT OF **232** C TO **260** C AND END POINT OF **343** C TO **371** C.

RESIDUAL FUELS, NO. 4 OR NO. 5 — ARE SUITABLE ONLY FOR THE SLOWER-SPEED DIESEL.

COMPOSITION OF FUELS

PARAFFINS	C_nH_{2n+2}	**SATURATED** HYDROCARBONS, VERY STABLE IN CHARACTERS
OLEFINS	C_nH_{2n}	**UNSATURATED HYDROCARBONS,** CHARACTERIZED BY THE PRESENCE OF A DOUBLE BOND BETWEEN CARBON ATOMS.
DIOLEFINS	C_nH_{2n-2}	**LESS SATURATED THAN OLEFINS,** CHARACTERIZED BY THE PRESENCE OF TWO DOUBLE BONDS

ADDITIONAL INFORMATION!!!

ADDITIVES

- INHIBIT OR SLOW DOWN OXIDATION
- INCREASE FILM STRENGTH
- KEEP SOLIDS IN FINELY DIVIDED STATE AND TO HOLD THEM IN SUSPENSION
- IMPROVE THE VISCOSITY INDEX
- LOWER THE POUR POINT
- DECREASE FRICTION AND WEAR UNDER EXTREME PRESSURE CONDITIONS
- REDUCE FOAMING
- RUST OR CORROSION INHIBITORS.

SAE NUMBERS — ARE A MEANS OF COORDINATING AND STANDARDIZING THE PRODUCTS OF OIL COMPANIES AND THE RECOMMENDATIONS BY THE OIL COMPANIES. THE SYSTEM OF SAE MOTOR CLASSIFICATION IS A SYSTEM **BASED ENTIRELY ON VISCOSITY** AND IS TOTALLY UNRELATED THE OTHER QUALITIES OF A LUBRICATING OIL.

PROPERTIES OF FUELS AND LUBRICANTS

1. ANALYSIS OF COMPOSITION

PROXIMATE ANALYSIS – IS MADE BY **HEATING THE COAL UNTIL IT DECOMPOSES SUCCESSIVELY INTO THREE OF THE FOUR COMPLEX ITEMS OF PROXIMATE ANALYSIS**. THE FOURTH IS FOUND BY THE DIFFERENCE. A TYPICAL PROXIMATE ANALYSIS OF COAL DETERMINES THE PERCENTAGE OF MOISTURE, VOLATILE MATTER, FIXED CARBON, AND ASH.

A. MOISTURE – IS DETERMINED BY SUBJECTING A **1**-GRAM SAMPLE OF THE COAL TO A TEMPERATURE OF **220** F TO **230** F FOR A PERIOD OF EXACTLY **1** HOUR.
B. VOLATILE MATTER – CONSISTS OF HYDROGEN AND CERTAIN HYDROGEN-CARBON COMPOUNDS THAT CAN BE REMOVED FROM THE COAL MERELY BY HEATING IT.
C. ASH – IS PERFORMED BY HEATING THE SAMPLE OF COAL USED IN THE MOISTURE DETERMINATION TO A TEMPERATURE OF **1290** F TO **1380** F IN AN UNCOVERED CRUCIBLE, WITH GOOD AIR CIRCULATION, UNTIL THE COAL IS COMPLETELY BURNED.
D. FIXED CARBON – IS THE DIFFERENCE BETWEEN **100** % AND THE SUM OF THE PERCENTAGES OF MOISTURE, ASH, AND VOLATILE MATTER.

ULTIMATE ANALYSIS – ANALYSIS OF COMPOSITION OF FUEL WHICH GIVES, ON MASS BASIS, THE RELATIVE AMOUNTS OF CARBON, HYDROGEN, OXYGEN, NITROGEN, SULFUR, ASH, AND MOISTURE.

2. SPECIFIC GRAVITY AND DENSITY

$$sg_t = sg_{15.6}(CF)$$

$$sg_{liq.} = \frac{\rho_{liq.}}{\rho_{H_2O}} \qquad sg_{gas} = \frac{\rho_{gas}}{\rho_{air}}$$

SG AT TEMPERATURE (CORRECTION FACTOR)

SI UNIT: $CF = 1 - 0.00072(t - 15.6°C)$

ENGLISH UNIT: $CF = 1 - 0.0004(t - 60°F)$

INSTRUMENTS USED FOR MEASURING SPEC. GRAVITY:
HYDROMETER, PYCNOMETER, WESTPHAL BALANCE

AMERICAN PETROLEUM INSTITUTE GRAVITY UNIT, A P I

- IS THE ACCEPTED STANDARD BY THE PETROLEUM AND OIL INDUSTRY, IT WAS DRAWN UP TO **CORRECT VALUES MEASURED BY INCORRECTLY CALIBRATED HYDROMETERS**.

$$°API = \frac{141.5}{Sg@15.6} - 131.5 \quad \text{(FOR PETROLEUM PRODUCTS)}$$

BAUME GRAVITY UNIT, B A U M E' O R B E'

- ANOTHER STANDARD COMMONLY ASSOCIATED **WITH BRINE**.

$$°Be = \frac{140}{Sg@15.6} - 130 \quad \text{(FOR BRINE)}$$

3. HEATING VALUE OR CALORIFIC VALUE

A. HIGHER HEATING VALUE (*GROSS* CALORIFIC VALUE), H H V

- IS THE HEATING VALUE OBTAINED WHEN THE WATER IN THE PRODUCTS OF COMBUSTION IS IN THE **LIQUID STATE**.

DULONGS (SOLID FUELS OF KNOWN ULT. ANALYSIS)	$33{,}820(C) + 144{,}212\left(H - \frac{O}{8}\right) + 9{,}304(S)$ KJ/kg
ASME FORMULA (PETROLEUM)	$41{,}130 + 139.6(°API)$ KJ/kg
BUREAU OF STANDARDS	$51{,}716 - 8793.8(sg)^2$ KJ/kg
S & K FORMULA	$42{,}450 - 93(°Be + 10)$ KJ/kg
FOR HYDROCARBONS	$13{,}500(C) + 60{,}890(H)$ $\frac{BTU}{lb}$

B. LOWER HEATING VALUE (*NET* CALORIFIC VALUE), L H V

– IS THE HEATING VALUE OBTAINED WHEN THE WATER IN THE PRODUCTS OF COMBUSTION IS IN THE **VAPOR STATE**.

WHERE: $Q_L = Q_H - 9H_2(2442)$

$H_2 = 26 - 15(S.g.)$; %

4. VISCOSITY

CENTIPOISES AND CENTISTOKES ARE MORE COMMONLY USED.

S A Y B O L T VISCOSIMETER

– MEASURES **THE TIME REQUIRED** FOR A GIVEN QUANTITY OF OIL AT STANDARD TEMPERATURE TO FLOW **THROUGH A SPECIFIED TUBE**.

S S U (SAYBOLT SECOND UNIVERSAL)

– IS **OBTAINED BY TIMING THE INTERVAL REQUIRED FOR 60 CC OF OIL TO** FLOW THROUGH TUBE OR PASS THROUGH A STANDARD ORIFICE.

FOR 30 – 45 SSU @ 37.8°C, CENTISTOKES $= 0.308(SSU - 26)$

$M_K = 0.22\,SSU - \frac{180}{SSU}$ UNIT: CENTISTOKES

S S F (SAYBOLT SECOND FUROL)

– UNIT USED FOR VERY VISCOUS LIQUIDS USING A RELATIVELY LARGE ORIFICE.

$$625SF = 6000SU$$

OTHER PROPERTIES...

FLASH POINT	THE TEMPERATURE AT WHICH OIL GIVES OFF VAPOR THAT **BURNS TEMPORARILY** WHEN IGNITED
FIRE POINT	IS THE TEMPERATURE AT WHICH OIL GIVES OFF VAPOR THAT **BURNS CONTINUOUSLY** WHEN IGNITED
POUR POINT	IS THE TEMPERATURE AT WHICH OIL **WILL NO LONGER POUR FREELY** OR THE TEMPERATURE AT WHICH OIL WILL SOLIDIFY
DROPPING POINT	IS THE TEMPERATURE AT WHICH **GREASE MELTS**
CLOUD POINT	IS THE TEMPERATURE AT WHICH THE **PARAFFIN ELEMENTS SEPARATE FROM OIL**
ANILINE POINT	IS THAT TEMPERATURE WHERE EQUAL PARTS **IF OIL AND ANILINE WILL DISSOLVE** IN EACH OTHER
CONRADSON NUMBER (CARBON RESIDUE)	IS THE CARBONACEOUS **RESIDUE REMAINING AFTER DESTRUCTIVE DISTILLATION**, EXPRESSED IN PERCENTAGE BY WEIGHT OF THE ORIGINAL SAMPLE.
OCTANE NUMBER	THE IGNITION QUALITY RATING OF **GASOLINE**, WHICH IS THE PERCENTAGE BY VOLUME OF ISO-OCTANE IN A MIXTURE
CETANE NUMBER	THE IGNITION QUALITY RATING OF **DIESEL**, WHICH IS THE PERCENT OF CETANE IN THE STANDARD FUEL
VISCOSITY INDEX	INDICATES THE RELATIVE **CHANGE IN VISCOSITY** OF AN OIL **FOR A GIVEN TEMPERATURE CHANGE**
VOLATILITY	IS THE ABILITY OF A LIQUID FUEL TO **CHANGE INTO VAPOR** WHICH IS MANIFESTED IN THE TEMPERATURE RANGE AT WHICH VARIOUS PORTIONS OF THE FUEL ARE VAPORIZED

FUEL PRODUCTION PROCESS

A. FRACTIONAL DISTILLATION

– THE PRIMARY METHOD OF **CRUDE OIL REFINING**.

B. THERMAL CRACKING

– CHANGING **HEAVY OIL INTO GASOLINE** BY MEANS OF HIGH PRESSURE, HIGH TEMPERATURE AND LONGER EXPOSURE TIME.

C. CATALYTIC CRACKING

– SUBJECTS OIL TO HIGH PRESSURE AND HIGH TEMPERATURE IN THE PRESENCE OF A **CATALYST**; PERMIT ACCURATE CONTROL OF THE COMPOUNDS FORMED AND **PRODUCES A GASOLINE OF HIGHER OCTANE NUMBER** THAN THE ONE PRODUCED IN THERMAL CRACKING.

D. HYDROGENATION

– PROCESS OF **CATALYTIC CRACKING IN A HYDROGEN ATMOSPHERE**; OBTAINED ARE **MORE SATURATED PRODUCTS THAN THOSE FROM CRACKING PROCESS** ALONE.

E. ISOMERIZATION

– PROCESS BY WHICH THE ATOMS OF CARBON AND HYDROGEN IN NORMAL HYDROCARBONS ARE **REARRANGED TO PRODUCE A MORE COMPLEX STRUCTURE OF HIGHER ANTI-KNOCK VALUE**.

F. POLYMERIZATION

– MAKES USE OF HIGH PRESSURE, HIGH TEMPERATURE AND A CATALYST TO COMBINE **LIGHT AND VOLATILE GASES INTO GASOLINE**.

G. ALKYLATION

– PROCESS OF COMBINING AN ISOPARAFFIN USUALLY ISO-BUTANE, WITH AN OLEFIN, USUALLY BUTANE OR PROPANE, TO FORM A LARGE ISOPARAFFIN MOLECULE, USUALLY ISO-OCTANE OR ISO-HEPTANE, HAVING A **VERY HIGH OCTANE NUMBER**.

H. REFORMING

– USED TO OBTAIN FUELS WITH **SUBSTANTIALLY HIGHER THAN 100 OCTANE NUMBER**; CURRENTLY USED TO PROCESS ABOUT FORTY PERCENT OF MOTOR GASOLINE.

I. HYDRODESULFURIZATION

– PROCESS OF **ADDING HYDROGEN TO UNSATURATED HYDROCARBONS AND REDUCING THE SULFUR CONTENT** OF THE RESULTING FUEL OIL.

COMBUSTION

- CHEMICAL **REACTION BETWEEN FUEL AND OXYGEN** (AIR) WHICH IS ACCOMPANIED BY HEAT AND LIGHT.

COMBUSTION OF SOLID FUELS

THEORETICAL WEIGHT OF AIR

- IF ULTIMATE ANALYSIS IS GIVEN

$$\left(\frac{A}{F}\right)_T = 11.5C + 34.5\left(H - \frac{O}{8}\right) + 4.3S \; ; \frac{kg_{air}}{kg_{fuel}}$$

- NOT AVAILABLE (ULTIMATE ANALYSIS)

$$\left(\frac{A}{F}\right)_t = \frac{Qh\ (kJ/kg)}{3117} \; ; \frac{kg_{air}}{kg_{fuel}}$$

ACTUAL WEIGHT OF AIR

$$\left(\frac{A}{F}\right)_a = \left(\frac{A}{F}\right)_t (1 \pm e)$$

ANALYSIS OF FLUE GAS

$$CO_2 + CO + O_2 + N_2 = 100\%$$

► DRY FLUE GAS (WITHOUT H_2O)

WEIGHT OF GASEOUS PRODUCTS

$$W_{fg} = W_a + W_f \; ; kg/hr$$

WEIGHT OF DRY FLUE GAS PER KG OF FUEL:

$$W_{dg} = \left(\frac{A}{F}\right)_a + 1 - (SO_2 + H_2O + ASH\ LOSS)$$

WHERE ;

$$SO_2 = \frac{2\%S}{100} \qquad ASH\ LOSS = \frac{\%ASH}{100}$$

$$H_2O = \frac{9\%H}{100}$$

COMBUSTION OF HYDROCARBON FUELS

$$\text{FUEL} + \text{AIR} \xrightarrow{\Delta} \text{COMBUSTION PRODUCTS}$$

COMPOSITION OF AIR

- BY WEIGHT (GRAVIMETRIC)

$$23\%\ O_2 + 77\%\ N_2$$

- BY VOLUME

$$21\%\ O_2 + 79\%\ N_2$$

▶ MOLAL RATIO: $\frac{\text{MOLES } N_2}{\text{MOLES } O_2} = \frac{79}{21} = 3.76$

AIR TO FUEL RATIO

- $\left(\frac{A}{F}\right)_{VOL} = \left(\frac{A}{F}\right)_{mol} = \frac{\text{NO. OF MOLES OF AIR}}{\text{NO. OF MOLES OF FUEL}}$
- $\left(\frac{A}{F}\right)_m = \frac{\text{MASS OF AIR}}{\text{MASS OF FUEL}}$

CONSTANTS!!

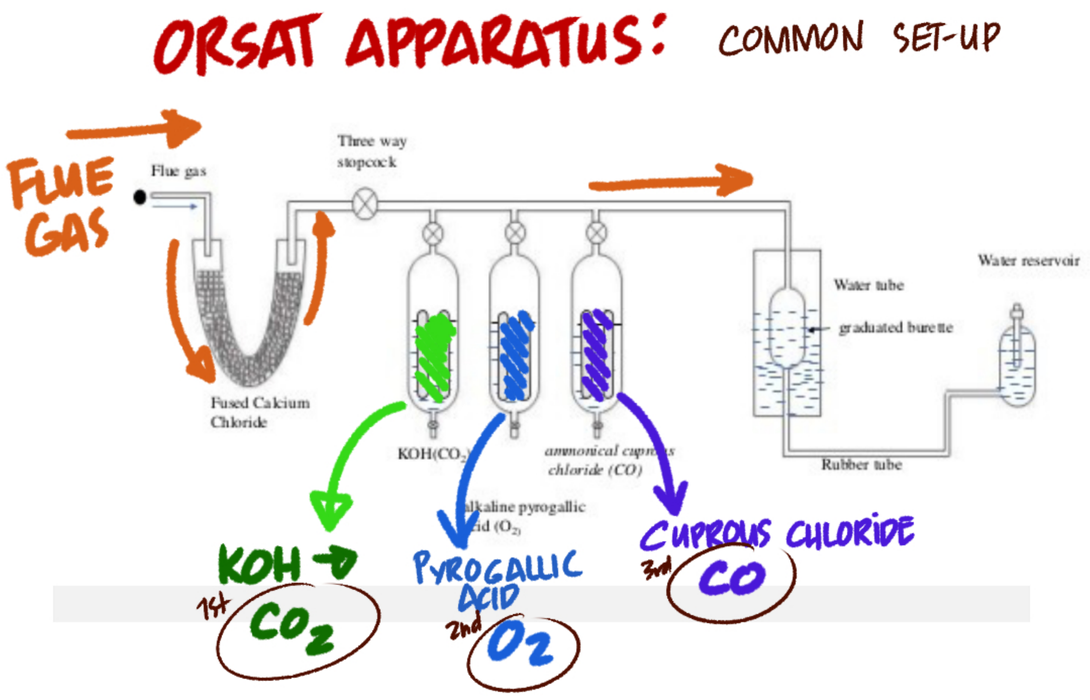
HYDROGEN = 1
CARBON = 12
NITROGEN = 14
OXYGEN = 16

CONDITION	FORMULA			CONSTANT
THEORETICAL (100% AIR)	REGULAR HCF	VALUE OF a: $n+\frac{m}{4}$	$C_nH_m + a(O_2+3.76N_2) \xrightarrow{\Delta} bH_2O + cCO_2 + dN_2$	BASIC!!
	ALCOHOL	$n+\frac{m}{4}-\frac{o}{2}$		
EXCESS AIR	$C_nH_m + (1+e)a(O_2+3.76N_2) \rightarrow bH_2O + cCO_2 + dN_2 + fO_2$			a, b, c
INSUFFICIENT AIR	$C_nH_m + (1-e)a(O_2+3.76N_2) \rightarrow bH_2O + cCO_2 + dN_2 + fCO$			a, b
INCOMPLETE COMBUSTION	$C_nH_m + (1-e)a(O_2+3.76N_2) \rightarrow bH_2O + cCO_2 + dCO + fO_2 + gN_2$			a, b

ORSAT APPARATUS

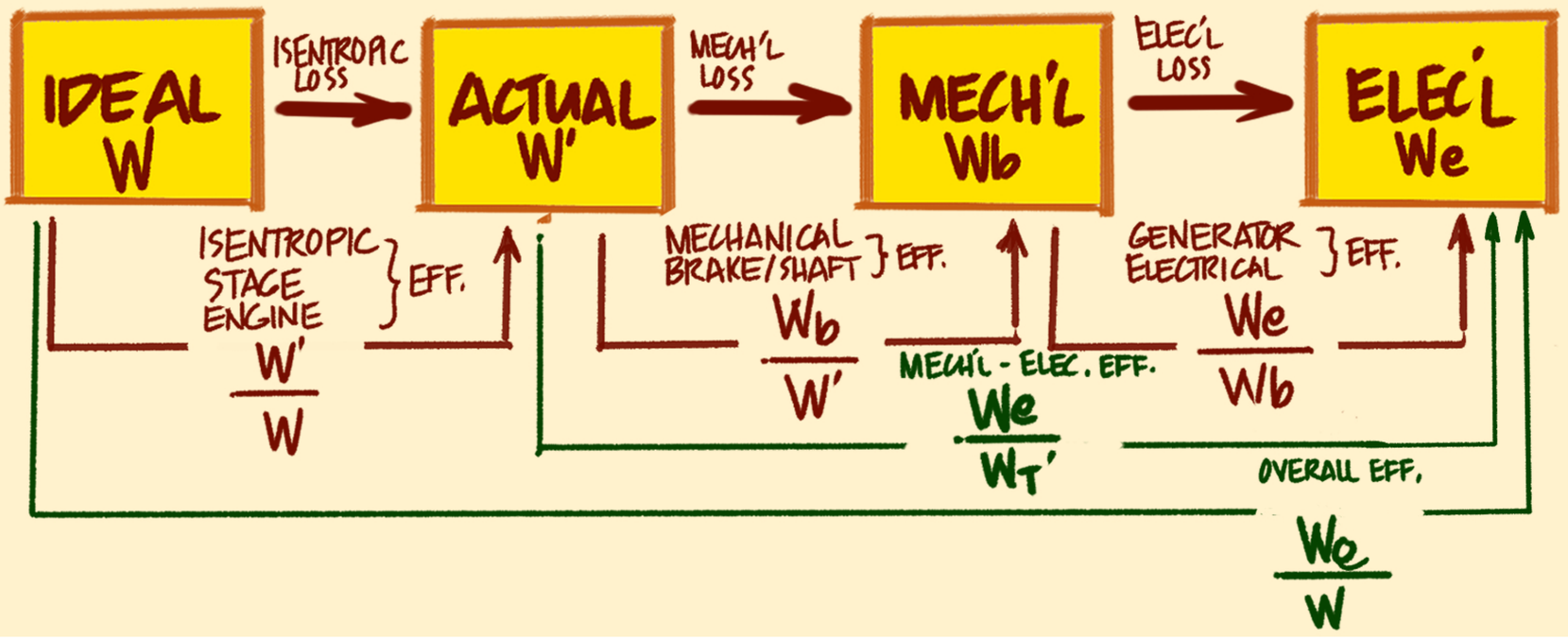
IS A CONVENIENT PORTABLE APPARATUS FOR DETERMINING THE VOLUMETRIC PERCENTAGE OF **CARBON DIOXIDE, OXYGEN GAS, AND CARBON MONOXIDE** IN THE DRY FLUE GAS.

PIPETTE 1: CONTAINS 'KOH' (CAUSTIC SODA) TO ABSORB **CO2** (CARBON DIOXIDE)
PIPETTE 2: CONTAINS AN ALKALINE SOLUTION OF 'PYROGALLIC ACID' TO ABSORB **O2** (OXYGEN)
PIPETTE 3: CONTAIN AN ACID SOLUTION OF 'CUPROUS CHLORIDE' TO ABSORB **CO** (CARBON MONOXIDE)



POWER PLANT BASICS

ENGINE EFFICIENCIES



THERMAL EFFICIENCIES

1. COMBINED CYCLE THERMAL EFF.

$$e_o = \frac{W_o}{Q_A} \times 100\%$$

2. ENGINE THERMAL EFF.

$$e_t = \frac{W}{E_c} \times 100\%$$

INDICATED (ACTUAL)
3. ENGINE THERMAL EFF.

$$e_{ti} = \frac{W'}{E_c} \times 100\%$$

4. BRAKE ENGINE THERMAL EFF.

$$e_{tb} = \frac{W_b}{E_c} \times 100\%$$

5. COMBINED ENGINE THERMAL EFF.

$$e_{to} = \frac{W_e}{E_c} \times 100\%$$

NOTE :

E_c = ENERGY CHARGEABLE (FOR THERMAL)

Q_A = HEAT ADDED (FOR CYCLE)

SPECIFIC FUEL CONSUMPTION AND STEAM RATE

SR = STEAM RATE

$$SR = \frac{m_s}{W_{net}} \; ; \frac{kg/s}{kW}$$

$$= \frac{m_s \times 3600}{W_{net}} \; ; \frac{kg}{kWhr}$$

$$= \frac{3600}{\dot{W}_{net}} \; ; \frac{kg}{kWhr}$$

NOTE:
- W = WORK ; kW
- $\dot{W}$ = SPECIFIC WORK ; $\frac{kJ}{kg}$

$$SR = \frac{m_s \times 3600}{W}$$

$$SR = \frac{3600}{\dot{W}}$$

REPLACE!!

1. ISR - INDICATED STEAM RATE
2. BSR - BRAKE STEAM RATE
3. CSR - COMBINED STEAM RATE

HEAT RATE

- RATE OF ENERGY CHARGE PER UNIT OF POWER
- RECIPROCAL OF THERMAL EFFICIENCY

HR = HEAT RATE

$$HR = \frac{E_c}{W_{net}} \; ; \frac{kJ/s}{kW}$$

$$= \frac{E_c \times 3600}{W_{net}} \; ; \frac{kJ}{kWhr}$$

ALSO;

$$HR = SR \times E_c$$

NOTE:
- W = WORK ; kW
- $\dot{W}$ = SPECIFIC WORK ; $\frac{kJ}{kg}$

$$HR = \frac{E_c \times 3600}{W_{net}} \; ; \frac{kJ}{kWhr}$$

REPLACE!!

1. IHR - INDICATED HEAT RATE
2. BHR - BRAKE HEAT RATE
3. CHR - COMBINED HEAT RATE

SHORTCUT:

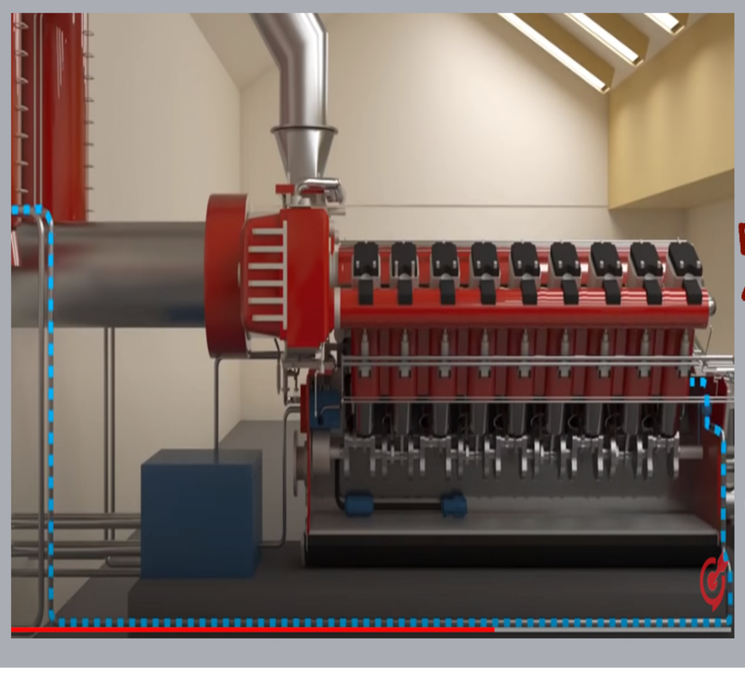
$$e_t = \frac{3600}{HR}$$

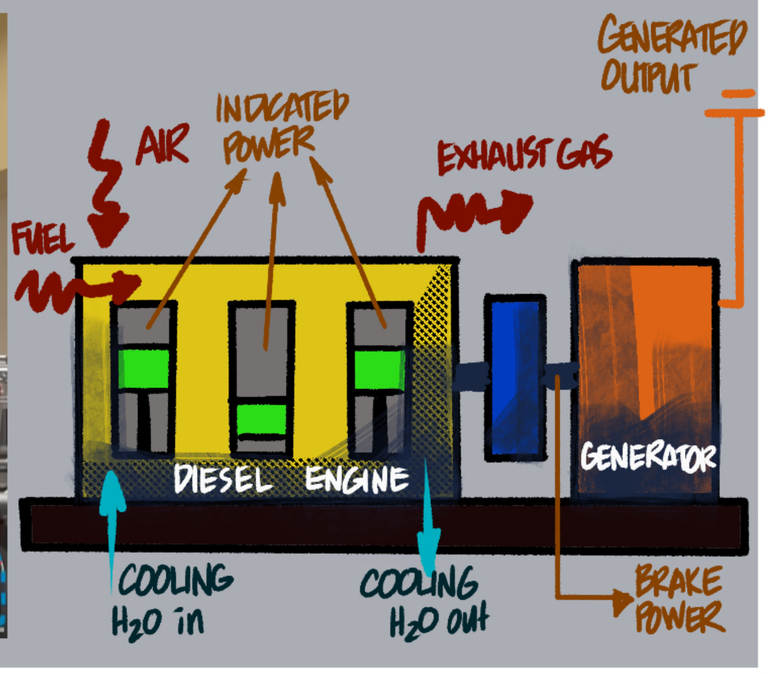
$$e_{ENGINE} = \frac{e_{THERMAL}}{e_{CYCLE}}$$

ENGISH:

$$e_t = \frac{2545}{HR}$$

DIESEL POWER PLANT





DIESEL ENGINE

IS AN EXCELLENT PRIME MOVER FOR ELECTRIC POWER GENERATION IN CAPACITIES OF **101** HP TO **5070** HP WHICH MAKES IT WIDELY-USED IN HOTELS, UTILITY COMPANIES, MUNICIPALITIES, AND PRIVATE INDUSTRIES.

RUDOLF CHRISTIAN KARL DIESEL

BASIC ELEMENTS IN PLANT DESIGN

STATIONARY DIESEL ENGINE	STRUCTURAL PARTS	BED PLATE
		FRAME
		LINERS
		HEAD
	MAJOR MOVING PARTS	PISTON
		CONNECTING RODS
		CRANKSHAFT
		BEARINGS
	ARRANGEMENTS FOR GETTING AIR IN AND EXHAUST OUT	VALVES
		VALVE MECHANISM
		MANIFOLD
		SCAVENGING
		SUPERCHANGING SYSTEMS
	FUEL-INJECTION SYSTEM	PUMPS
		NOZZLES
		CONTROL DEVICES
FUEL SYSTEM		FUEL STORAGE TANK
		FUEL FILTER
		FUEL PUMP
		DAY TANK
LUBRICATION SYSTEM		LUBE OIL TANK
		LUBE OIL PUMP
		OIL FILTER
		OIL COOLER
		LUBRICATORS
COOLING SYSTEM		COOLING WATER PUMP
		HEAT EXCHANGER
		COOLING TOWER
		SURGE TANK
INTAKE AND EXHAUST SYSTEMS		AIR FILTER
		SUPERCHARGER
		INTAKE PIPE
		EXHAUST PIPE
		EXHAUST SILENCER (TO MINIMIZE EXHAUST NOISE)
STARTING SYSTEM		AIR COMPRESSOR
		AIR STORAGE TANK
GOVERNING SYSTEM		

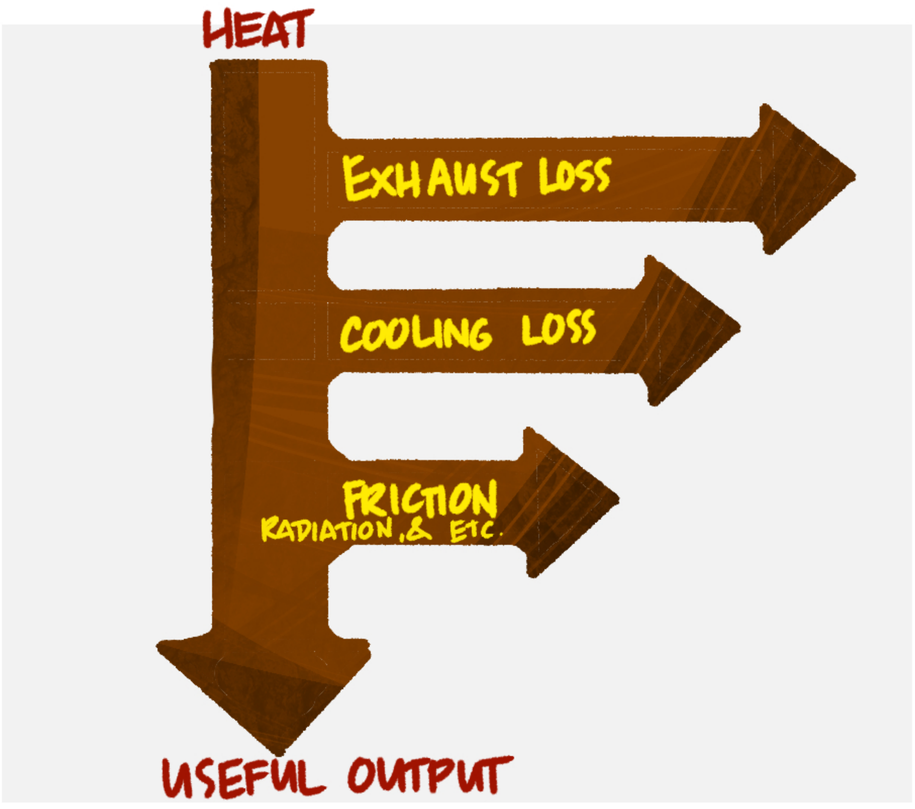
ADVANTAGES:

- ADVANTAGES OF THE DIESEL ENGINE:
- LOW FUEL COST.
- NO LONG WARMING-UP PERIOD.
- NO STANDBY LOSSES.
- UNIFORMLY HIGH EFFICIENCY OF ALL SIZES.
- SIMPLE PLANT LAYOUT.
- NEEDS NO LARGE WATER SUPPLY.

TYPICAL FULL-LOAD HEAT BALANCES (%) BASED ON HEATING VALUE OF FUEL.

ENERGY STREAM		DIESEL CYCLE	OTTO CYCLE
E	EXHAUST LOSS	26	37
C	COOLING LOSS	30	30
F	FRICTION LOSS, RADIATION, AND ETC.	10	8
U	UESFUL OUTPUT (BRAKE WORK)	34	25

ENERGY STREAM



1. EXHAUST LOSS (q_E)

$q_E = mc_{pg}\Delta T_g$

2. COOLING LOSS (q_{rc})

$q_c = m_w c_{pw} \Delta T_w$

3. FRICTION; RADIATION & UNACCTD, LOSSES

$= E_c - P_b - q_E - q_c$

MORE SPECIFIC APPROACH TO EXHAUST LOSS

q_E = SHL + LHL
- LHL → LATENT
- SHL → SENSIBLE

$SHL = m_g c_{pg} (t_g - t_a)$

$m_g = m_a + m_f = m_a\left(1 + \frac{m_f}{m_a}\right)$

$\frac{m_f}{m_a}$ = FUEL to AIR RATIO; f

AIR to FUEL RATIO $= m_f\left(\left(\frac{A}{F}\right) + 1\right)$

$LHL = 9H_2\, m_f\, (2442)\ ; \frac{kJ}{kg}$

$H_2 = 26 - 15(SG)\ ; \%$

S_g = SPECIFIC GRAVITY @ 15.6°C

COMPUTATION

HEAT SUPPLIED

$$Q_A = m_f Q_h = \text{ENERGY CHARGEABLE}$$

NOTE: FOR HEATING VALUE — REFER TO FUELS AND COMBUSTION

AIR-FUEL RATIO

$$\left(A/F\right) = \frac{\text{MASS OF AIR}}{\text{MASS OF FUEL}}$$

PISTON DISPLACEMENT

$$V_D = \frac{\pi D^2}{4} L \cdot N \cdot (n_c \cdot n_p)$$

- n_p → PISTON ACTIONS
- n_c → NO. OF CYLINDERS

FOR 4 STROKE ENGINE: $N = N/2$

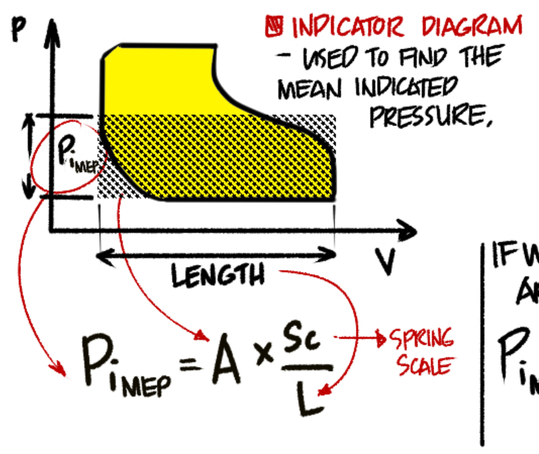
PISTON SPEED

$S_p = 2LN$ | DISTANCE TRAVELLED = $2L$

INDICATED POWER

POWER DEVELOPED INSIDE THE CYLINDER

- MEASURED BY AN INDICATOR



$P_{i_{MEP}} = A \times \frac{Sc}{L}$

$\text{POWER}_i = P_{i_{MEP}} V_D$

IF WORKING CYLINDER & CRANKCASE ARE CONSIDERED;

$P_{i_{MEP}} = \left(A \cdot \frac{Sc}{L}\right)_{VC} - \left(A \cdot \frac{Sc}{L}\right)_{CC}$

BRAKE POWER

- SHAFT POWER
- CALCULATED USING PRONY BRAKE/ DYNAMOMETER

$P_b = 2\pi TN$ (T = Fr)

ALSO; $P_b = P_{b_{MEP}} V_D$

FRICTION POWER

FRICTION POWER, FP, IS CONSTANT NO MATTER HOW MANY CYLINDERS ARE FIRING.

$P_f = P_i - P_b$

- P_f → ALWAYS CONSTANT!!
- P_b → BRAKE POWER
- P_i → INDICATED POWER

MECH. EFFICIENCY

$$e_m = \frac{P_b}{P_i} = \frac{P_{b\,MEP}}{P_{i\,MEP}}$$

ELECTRICAL EFFICIENCY

$$e_e = \frac{P_e}{P_b}$$

THERMAL EFFICIENCY

$$e_t = \frac{P}{m_f Q_h}$$

P_i = INDICATED T.E.
P_b = BRAKE T.E.
P_o = COMBINED T.E.

ENGINE EFFICIENCY

$$e_e = \frac{e_t}{e}$$ ⇝ IDEAL THERMAL EFF.

CYCLE EFFICIENCY

$$= \frac{\text{WORK}}{Q_A}$$

VOLUMETRIC EFFICIENCY

$$e_v = \frac{V_{AIR}}{V_D}$$

→ VOLUME OF AIR DRAWN

$$V_a = \frac{m_a R_a T_a}{P_a}$$

GENERATOR SPEED

$$N = \frac{120f}{P}$$

N = IN RPM
f = IN HERTZ (REV/S) — USE 60HZ IF NOT GIVEN
P = NO. OF POLES

ENGINE OPERATING AT HIGHER ELEVATION

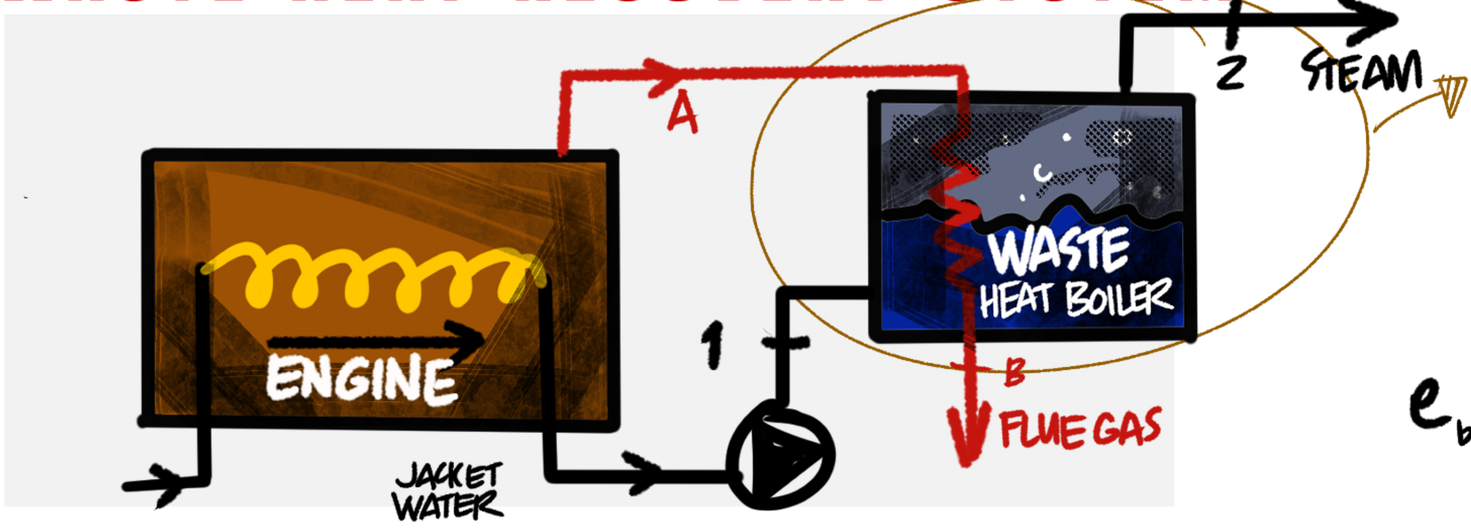
ENGINE CONSTANTS

FRICTION POWER	$P_{f_1} = P_{f_2}$
MAS OF FUEL CONSUMPTION	$m_{f_1} = m_{f_2}$
VOLUME OF AIR REQUIRED	$V_{a_1} = V_{a_2}$
INDICATED POWER IS DIRECTLY PROPORTIONAL TO DENSITY OF AIR	$\frac{P_{i_1}}{P_{i_2}} = \frac{\rho_{a_1}}{\rho_{a_2}}$

TEMPERATURE AND PRESSURE RELATIONS AT HIGHER ELEVATION

TEMP. EFFECT ALONE	$P_2 = P_1\sqrt{\frac{T}{520}}$ $T = 520 - \frac{3.6h}{1000}$; °R
PRESSURE EFFECT ALONE	$P_2 = P_1\left[\frac{\text{PRESSURE}}{29.92}\right]$ $\text{PRESSURE} = 29.92 - \frac{h}{1000}$; inHg
TEMPPERATURE AND PRESURE EFFECT	$P_2 = P_1\left[\frac{\text{PRESSURE}}{29.92}\right]\left[\sqrt{\frac{T}{520}}\right]$

WASTE HEAT RECOVERY SYSTEM



BY ENERGY BALANCE:

$$m_s(h_2 - h_1) = m_g c_{pg} \Delta t_g$$

$$m_s(h_s - h_f) = m_g c_{pg} \Delta t_g$$

$$e_{boiler} = \frac{q_s}{q_g} = \frac{m_s(h_s - h_f)}{m_g c_{pg} \Delta t_g}$$

ADDITIONAL INFORMATION!!!

GOVERNOR	**GOVERN OR CONTROL THE SPEED** OF AN ENGINE UNDER VARYING LOAD CONDITIONS
PURIFIER	**PURIFY** FUEL OIL AND LUBE OIL
GENERATOR	USED TO **CONVERT MECHANICAL ENERGY TO ELECTRICAL ENERGY**
COMBUSTION	PROCESS **OF CHEMICAL UNION** BETWEEN CERTAIN SUBSTANCE
THERMOCOUPLE	MADE OF ROD OF DIFFERENT METAL THAT ARE WELDED TOGETHER AT ONE END, MEASURES TEMPERATURE
CENTRIFUGE	PURIFICATION OF **OIL FOR SEPARATION OF WATER**
UNLOADER	DEVICE FOR **AUTOMATICALLY KEEPING PRESSURE CONSTANT BY CONTROLLING THE SUCTION VALVE**
PLANIMETER	TRACES THE **AREA** OF ACTUAL P-V DIAGRAM
TACHOMETER	**MEASURES SPEED** OF THE ENGINE (ROTATIONAL SPEED)
ENGINE INDICATOR	TRACES THE **ACTUAL P-V DIAGRAM**
DYNAMOMETER	MEASURES THE **TORQUE** OF THE ENGINE
BRIDGE GAUGE	USED TO FIND **THE RADIAL POSITION OF CRANKSHAFT** MOTOR SHAFT
PISTON	MADE OF CAST IRON OR ALUMINUM ALLOY HAVING A CYLINDER FORM
ATOMIZER	ATOMIZE THE FUEL INTO **TINY SPRAY** WHICH COMPLETELY FILL THE FURNACE OPENING IN THE FORTH OF HOLLOW CONE

PRINCIPLES

A. CRANKSCAVENGING

– ONE THAT THE CRANK CASE IS USED AS COMPRESSOR

B. SUPERCHARGING

– ADMITTANCE INTO CYLINDER OF AN AIR CHARGE WITH **DENSITY HIGHER THAN THAT OF THE SURROUNDING AIR**

WORKING **PRESSURE** IN POWER CYLINDER	50 – 500 psi
WORKING **TEMPERATURE** IN THE CYLINDER	800°F - 1000°F
AIR **PRESSURE USED IN AIR INJECTION** FUEL SYSTEM	600 psi – 1000 psi
AVERAGE **COMPRESSION RATIO** OF A DIESEL ENGINE	14 – 16

REASON FOR SUPERCHARGING:

A. TO REDUCE THE WEIGHT-TO-POWER RATIO.
B. TO COMPENSATE FOR POWER LOSS DUE TO HIGH ALTITUDE.

TYPES OF SUPERCHARGERS:

A. ENGINE-DRIVEN COMPRESSOR.
B. EXHAUST-DRIVEN COMPRESSOR (TURBO-CHARGER).
C. SEPARATELY-DRIVEN COMPRESSOR.

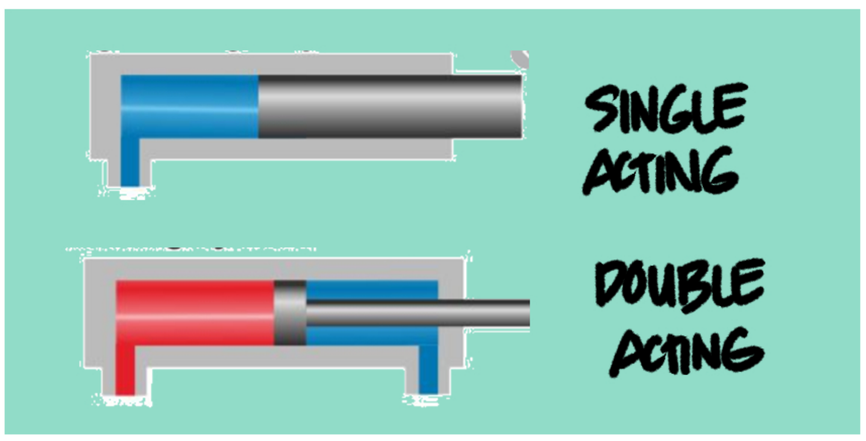
C. FLARE BACK

– IS DUE TO THE **EXPLOSION OF A MAXIMUM FUEL OIL VAPOR AND AIR IN THE FURNACE**

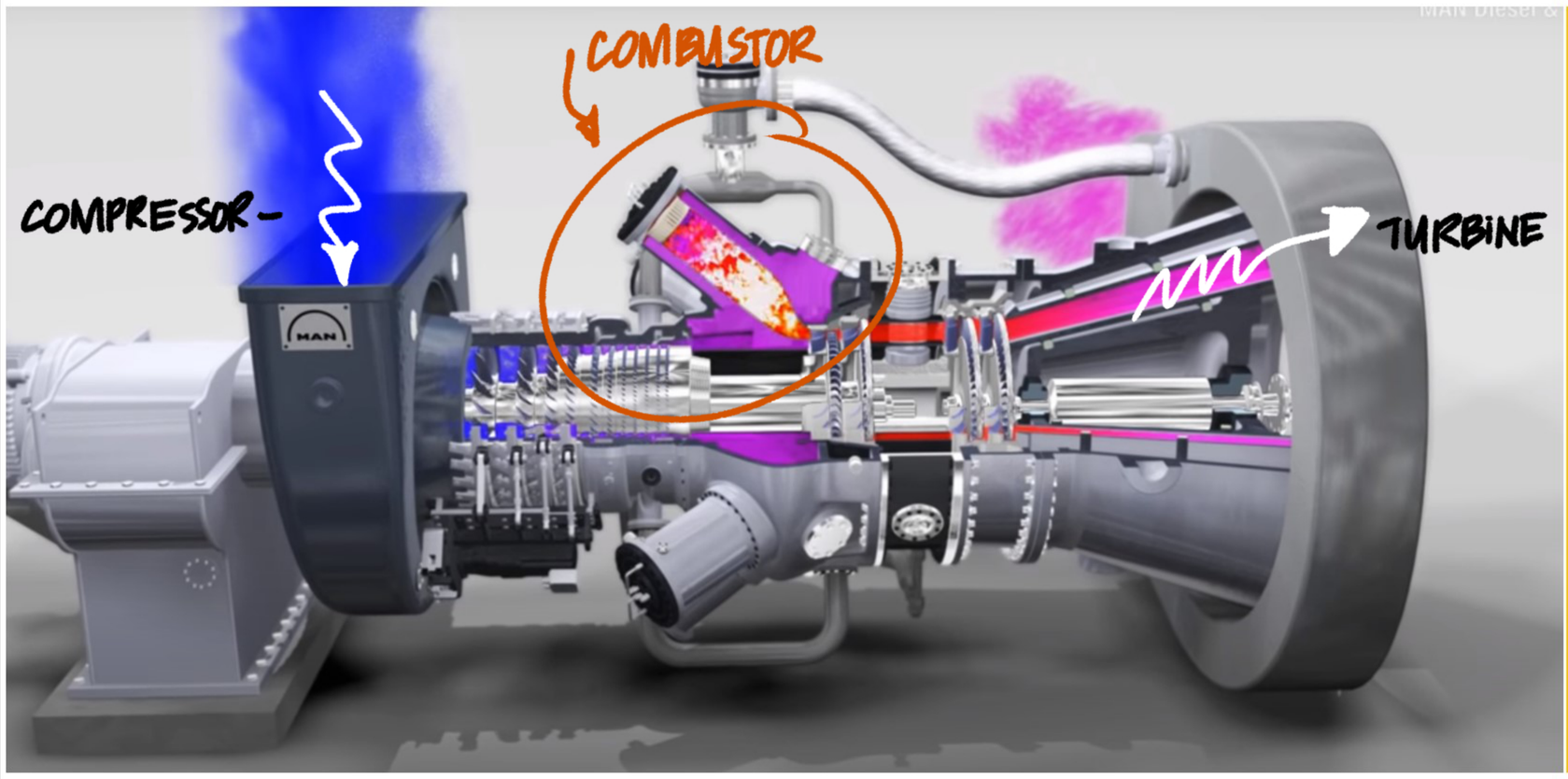
THE EFFECT OF **OVER LUBRICATING** A DIESEL ENGINE IS **CARBONIZATION OF OIL** ON VALVE SEATS AND POSSIBLE **EXPLOSIVE MIXTURE** IS PRODUCED.

SINGLE ACTING ENGINE VS. DOUBLE ACTING ENGINE. THE DIFFERENCE?

SINGE ACTING – ONE WORKING STROKE
DOUBLE ACTING – TWO WORKING STROKE



GAS TURBINE POWER PLANT



GAS TURBINE POWER

- ALSO KNOWN AS **BRAYTON CYCLE** OR **JOULE CYCLE**
- ICE AND LIGHTER AND MORE COMPACT THAT OTHER VAPOR POWER PLANTS
- SUITABLE FOR TRANSPORTATION APPLICATIONS, AIRCRAFTS, MARINE, AND ALSO FOR STATIONARY POWER PLANTS.

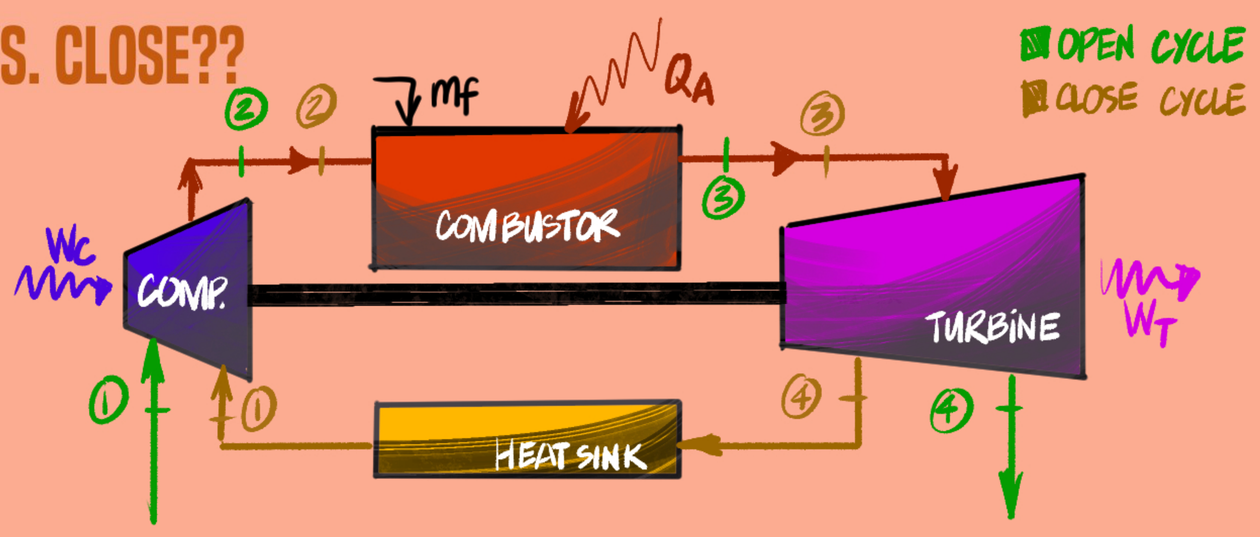
RANGE:

ABOVE 10 MW, LARGE APPLICATIONS OPERATE FROM 100 MW TO 230 MW.

GAS TURBINE CYCLE (IDEAL AND ACTUAL)

SCHEMATIC DIAGRAM

OPEN VS. CLOSE??

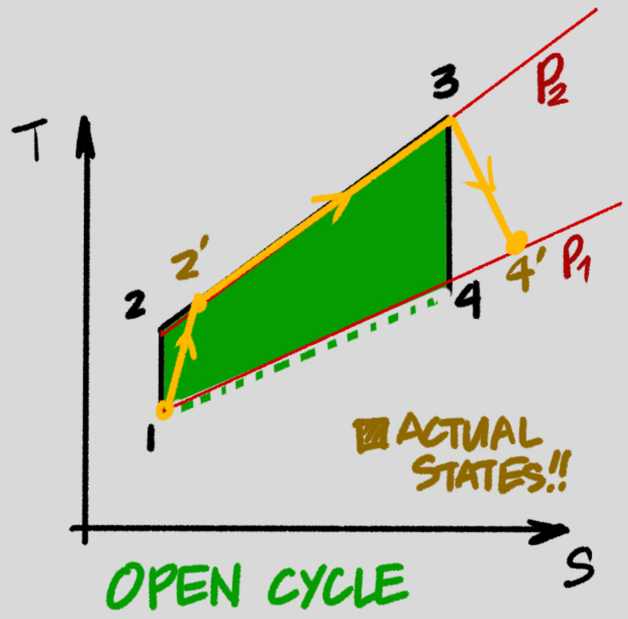


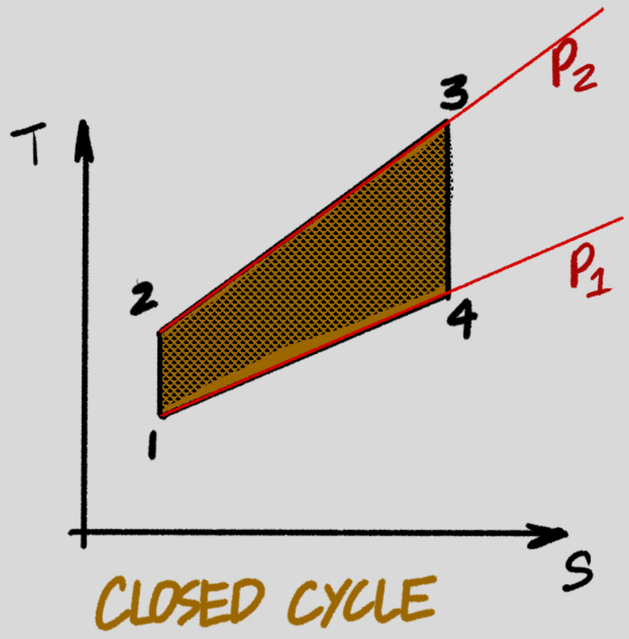
PROCESS

1-2	ISENTROPIC COMPRESSION
2-3	ISOBARIC HEAT ADDITION
3-4	ISENTROPIC EXPANSION
4-1	ISOBARIC HEAT REJECTION

↳ ONLY FOR CLOSED CYCLE

DIAGRAM



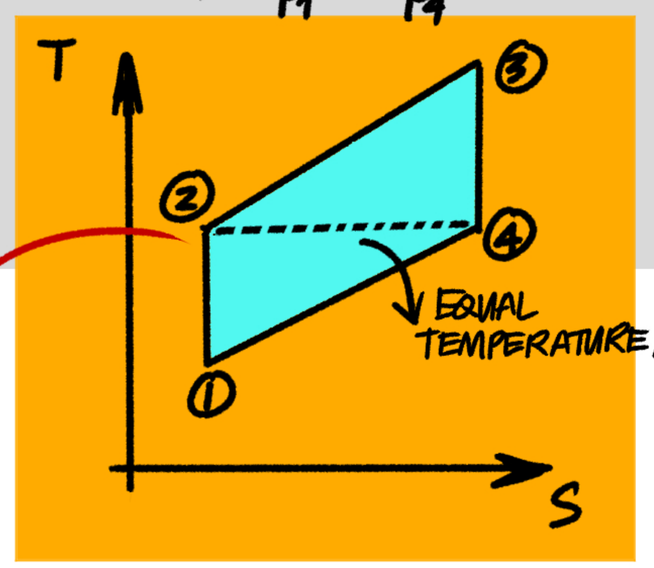


ANALYSIS:

PRESSURE RATIO = $\frac{P_2}{P_1}$

$$r_p = \frac{P_2}{P_1} = \left(\frac{T_2}{T_1}\right)^{\frac{k}{k-1}}$$

$$r_p = \frac{P_2}{P_1} \approx \frac{P_3}{P_4}$$



FOR MAXIMUM THEORETICAL NETWORK

$$T_2 = \sqrt{T_1 \times T_3}$$

OBSERVE THAT

$T_2 = T_4$

COMPUTATION

COMPRESSOR WORK

$$W_C = m_a c_{pa} (T_2 - T_1)$$

HEAT ADDED IN COMBUSTOR

NOTE: $m_g = m_a + m_f$

$$Q_a = m_g c_{pg} (T_3 - T_2)$$

TURBINE WORK

$$W_T = m_g c_{pg} (T_3 - T_4)$$

NET WORK TURBINE

$$W_{NET} = W_T - W_C$$

BACK WORK RATIO

$$BW_R = W_C / W_T$$

CYCLE EFFICIENCY

$$e_c = \frac{W_{NET}}{Q_A} = 1 - \frac{1}{r_p^{\frac{K-1}{K}}}$$

COMPRESSOR EFFICIENCY

$$e_{COMP.} = \frac{T_2' - T_1}{T_2 - T_1}$$

COMBUSTOR EFFICIENCY

$$e_{COMBUSTOR} = \frac{Q_{AIR}}{Q_{FUEL}}$$

OVERALL THERMAL EFFICIENCY

$$e_{to} = \frac{We}{mfQh}$$

NET PLANT HEAT RATE

$$NET\ HR = \frac{3600}{e_{to}}$$

NOTE:

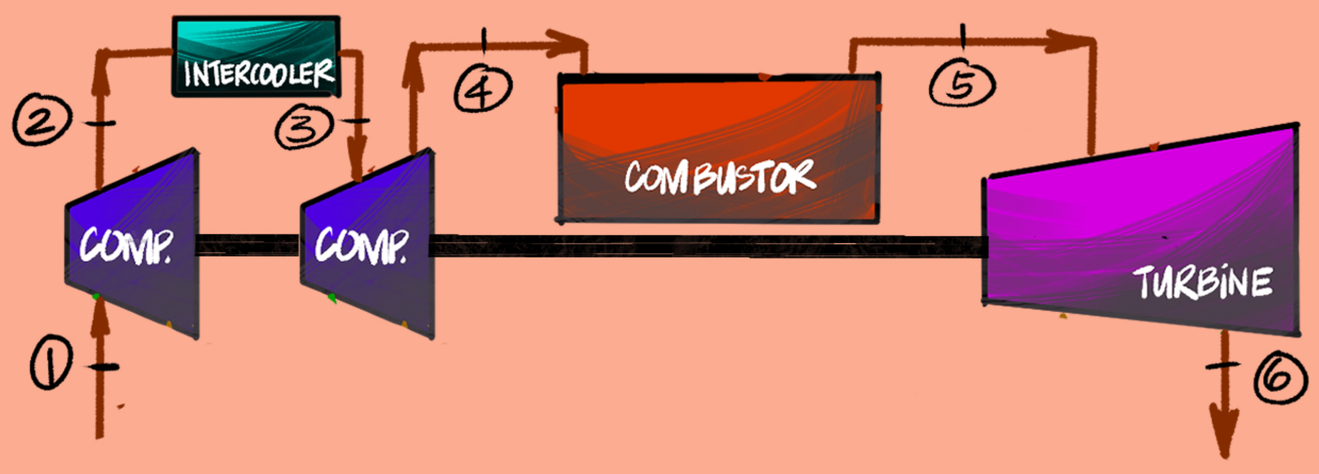
FOR ACTUAL PROCESSES; CHANGE

$T_2 \longrightarrow T_2'$

$T_4 \longrightarrow T_4'$

IMPROVEMENTS: MULTISTAGE COMPRESSION

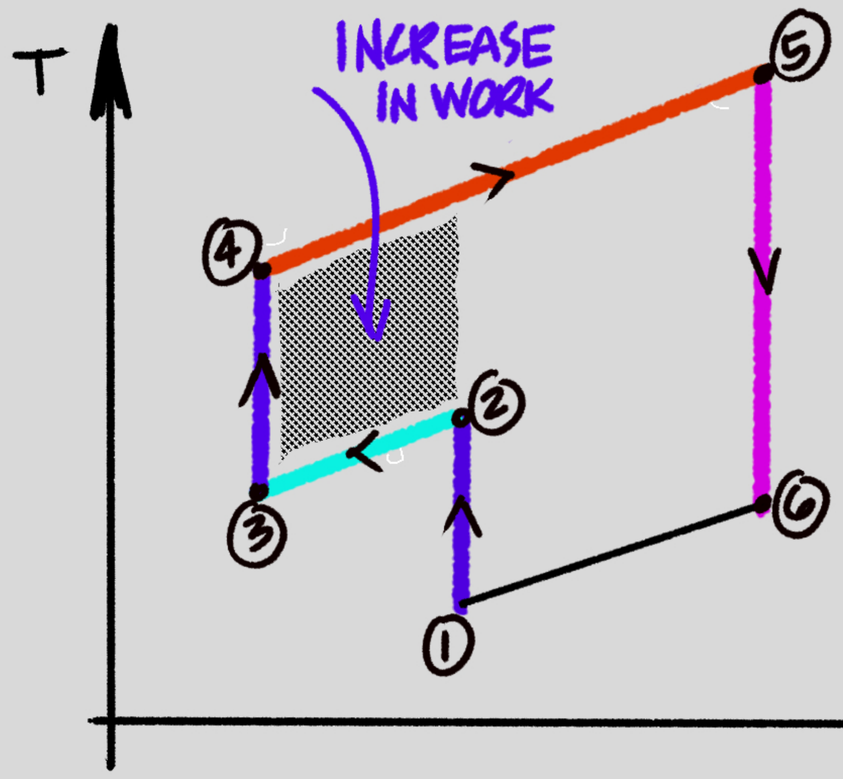
SCHEMATIC DIAGRAM



PROCESS

1-2	ISENTROPIC WORK (COMP.)
2-3	ISOBARIC COOLING
3-4	ISENTROPIC WORK (COMP.)
4-5	ISOBARIC HEATING
5-6	ISENTROPIC WORK (TUR.)

DIAGRAM



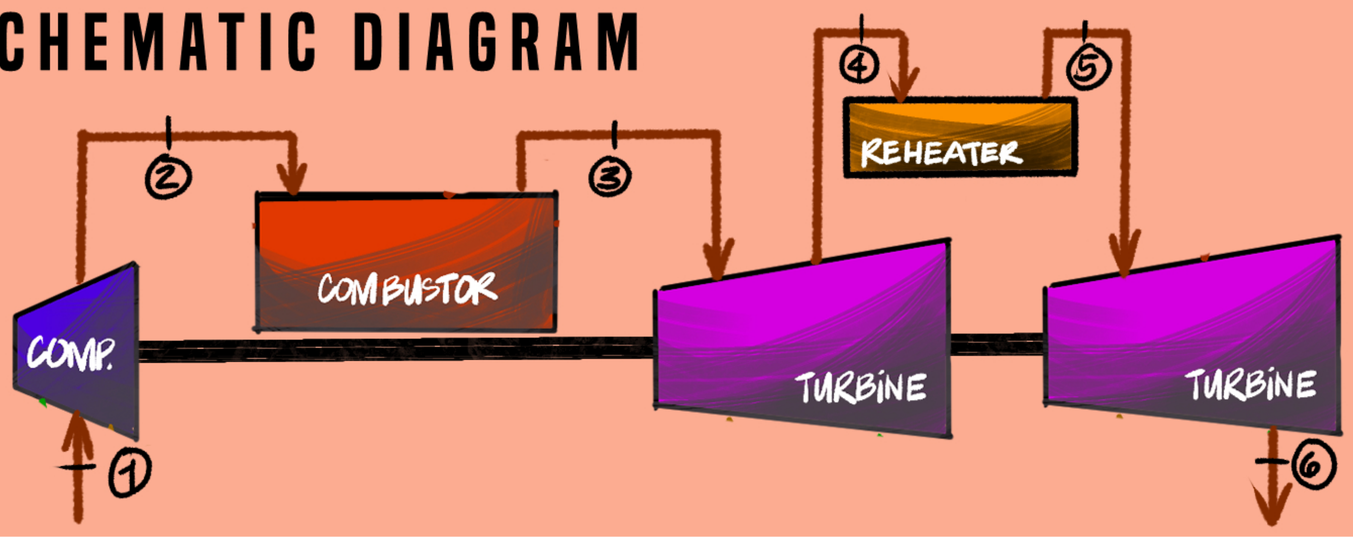
NOTE;

IF P_i (INTERCOOLER) IS NOT GIVEN:

$$P_i = \sqrt{P_1 \times P_4}$$

IMPROVEMENTS: WITH REHEAT

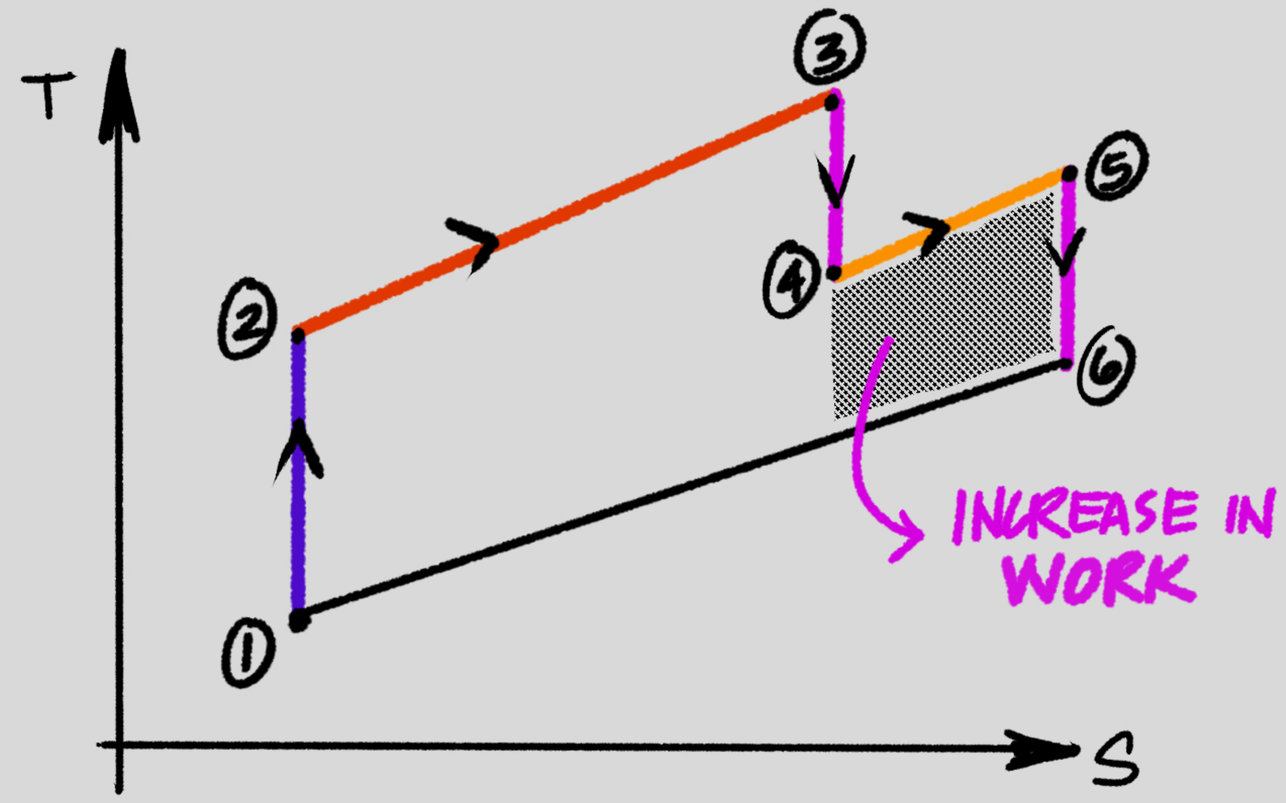
SCHEMATIC DIAGRAM



PROCESS

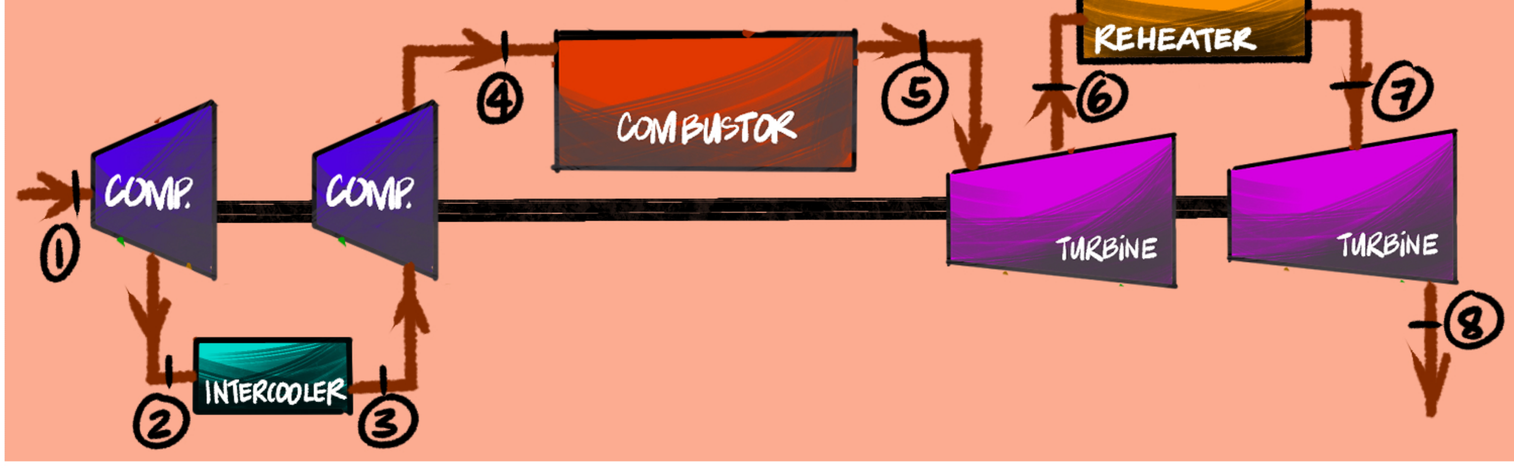
1-2	ISENTROPIC WORK (COMP.)
2-3	ISOBARIC HEATING
3-4	ISENTROPIC WORK (TUR.)
4-5	ISOBARIC HEATING
5-6	ISENTROPIC WORK (TUR.)

DIAGRAM



IMPROVEMENTS: MULTISTAGE COMPRESSION WITH REHEAT

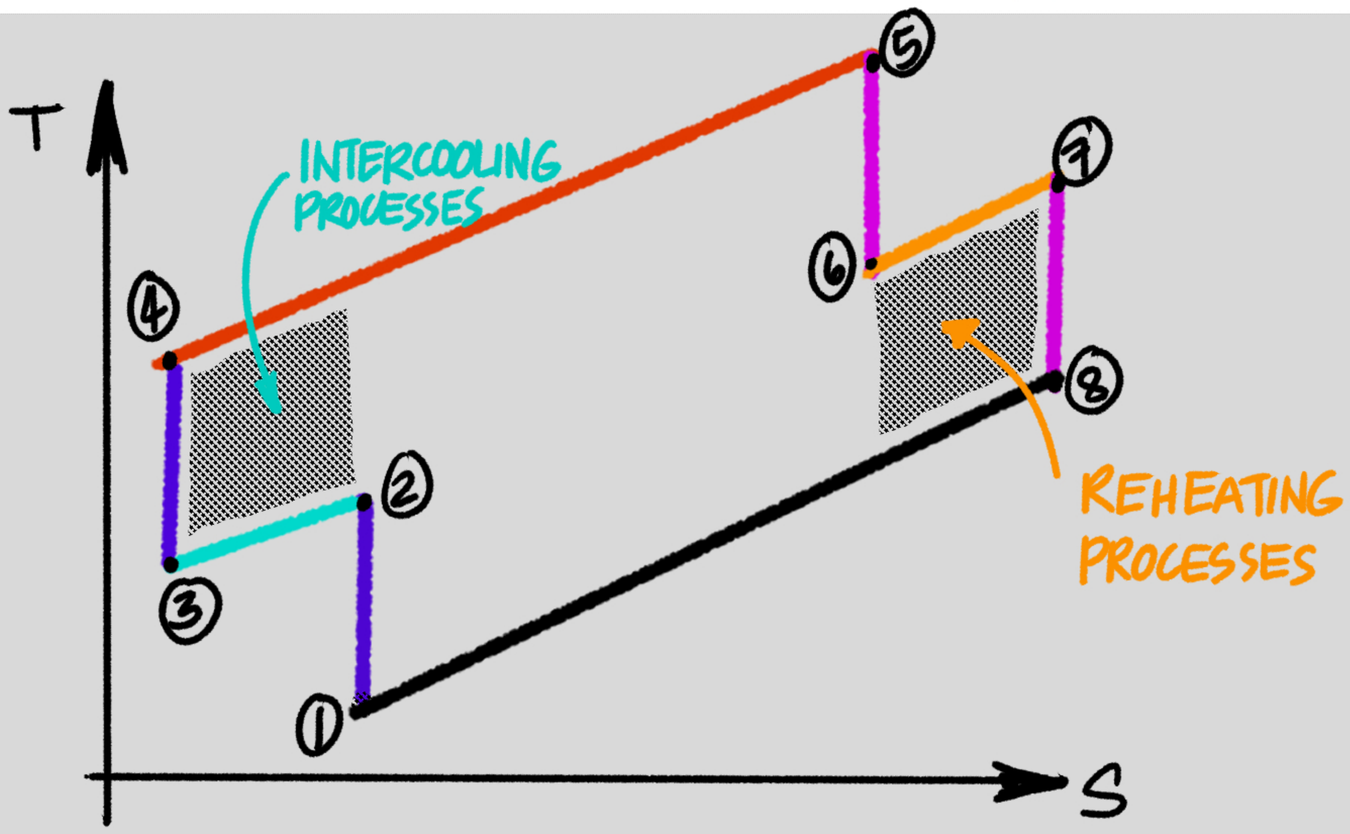
SCHEMATIC DIAGRAM



PROCESS

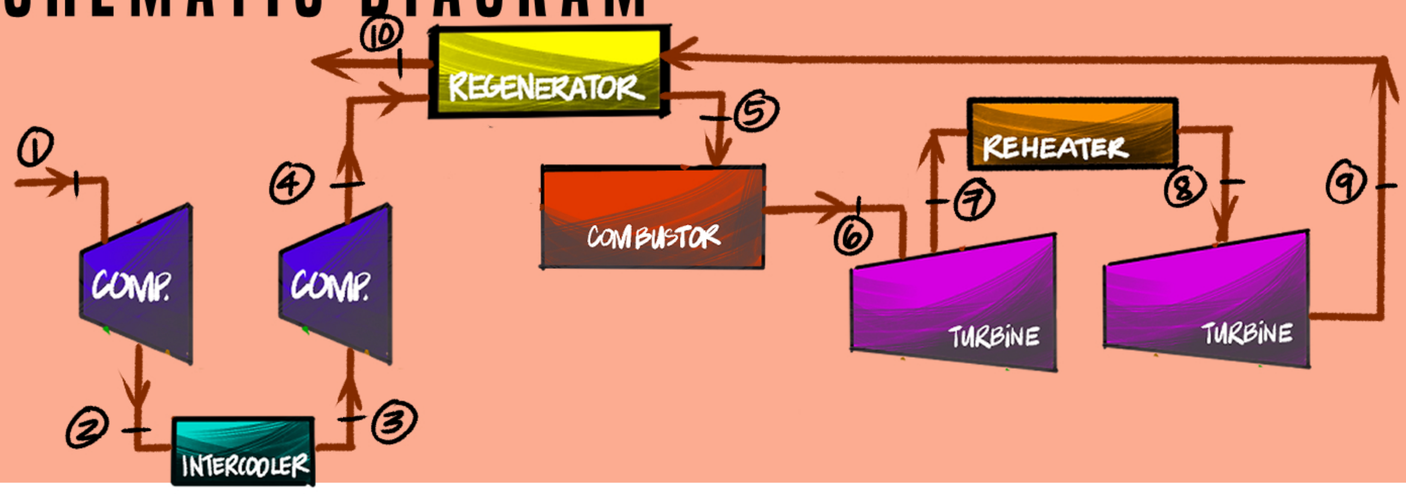
1-2	ISENTROPIC WORK (COMP.)
2-3	ISOBARIC COOLING (INT.)
3-4	ISENTROPIC WORK (COMP.)
4-5	ISOBARIC HEATING (COMB.)
5-6	ISENTROPIC WORK (TUR.)
6-7	ISOBARIC HEATING (REH.)
7-8	ISENTROPIC WORK (TUR.)

DIAGRAM



IMPROVEMENTS: MULTI-COMPRESSION, REHEAT, REGENERATIVE

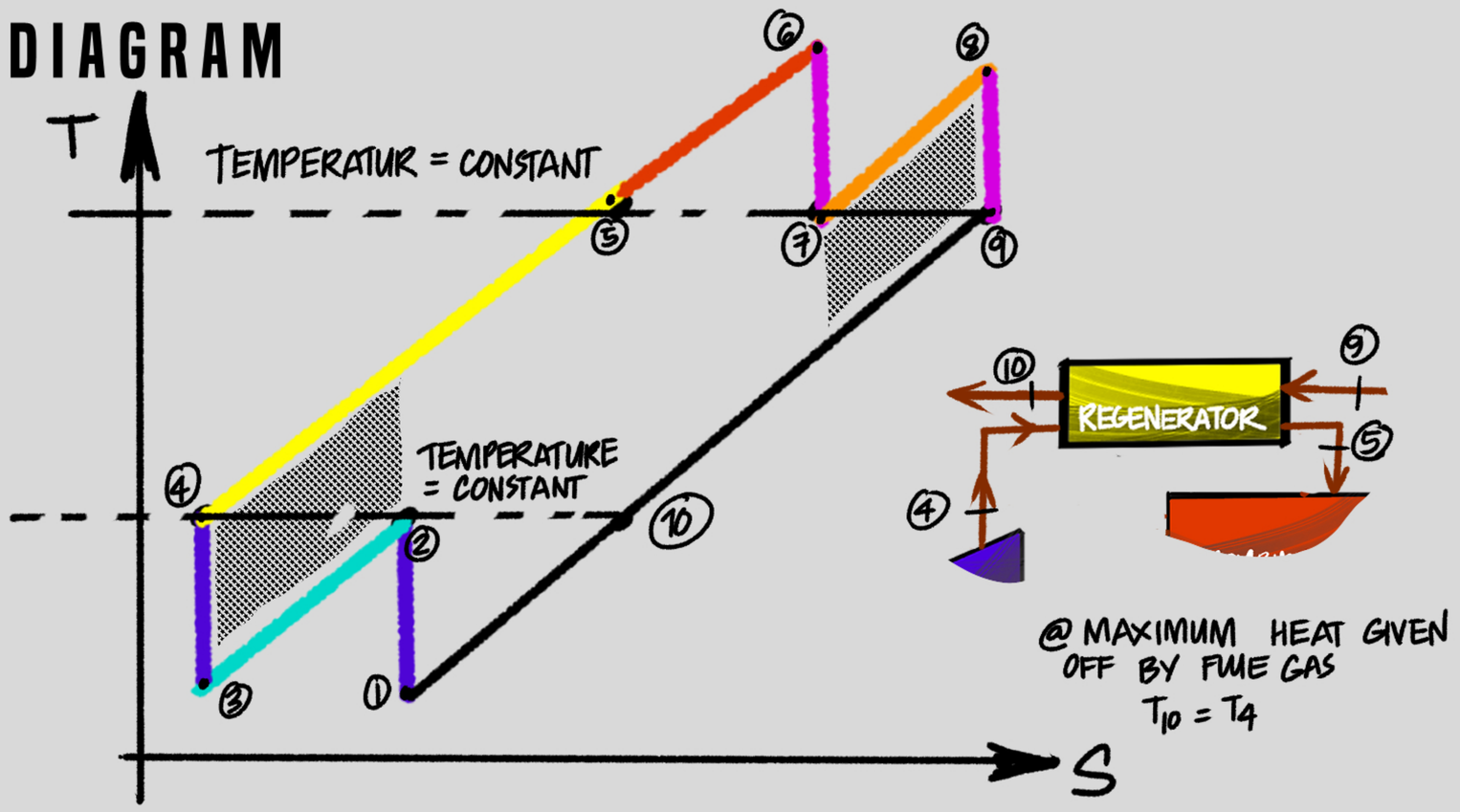
SCHEMATIC DIAGRAM



PROCESS

1-2	ISENTROPIC WORK (COMP.)
2-3	ISOBARIC COOLING (INT.)
3-4	ISENTROPIC WORK (COMP.)
4-5	ISOBARIC HEATING (REG.)
5-6	ISOBARIC HEATING (COMB.)
6-7	ISENTROPIC WORK (TUR.)
7-8	ISOBARIC HEATING (REH.)
8-9	ISENTROPIC WORK (TUR.)
9-10	ISOBARIC COOLING (REG.)

DIAGRAM



@ MAXIMUM HEAT GIVEN OFF BY FUE GAS

$T_{10} = T_4$

EFFECTIVENESS OF THE REGENERATOR

– IS DEFINED AS THE RATIO OF ACTUAL AMOUNT OF HEAT TRANSFERRED TO THE AMOUNT OF THAT COULD BE TRANSFERRED REVERSIBLY.

$$\text{EFFECTIVENESS} = \frac{\text{ACTUAL HEAT ABSORBED}}{\text{MAX. HEAT GIVEN OFF BY FLUE GAS}}$$

$$E = \frac{T_5 - T_4}{T_9 - T_4}$$

THERMAL REFINEMENT OF THE GAS TURBINE CYCLE

REGENERATION

– IS THE TRANSFER OF HEAT ENERGY **FROM EXHAUST GASES TO COMPRESSED AIR FLOWING BETWEEN THE COMPRESSOR AND COMBUSTION CHAMBER**. A SURFACE HEATER CALLED THE "REGENERATOR" IS REQUIRED.

INTERCOOLING

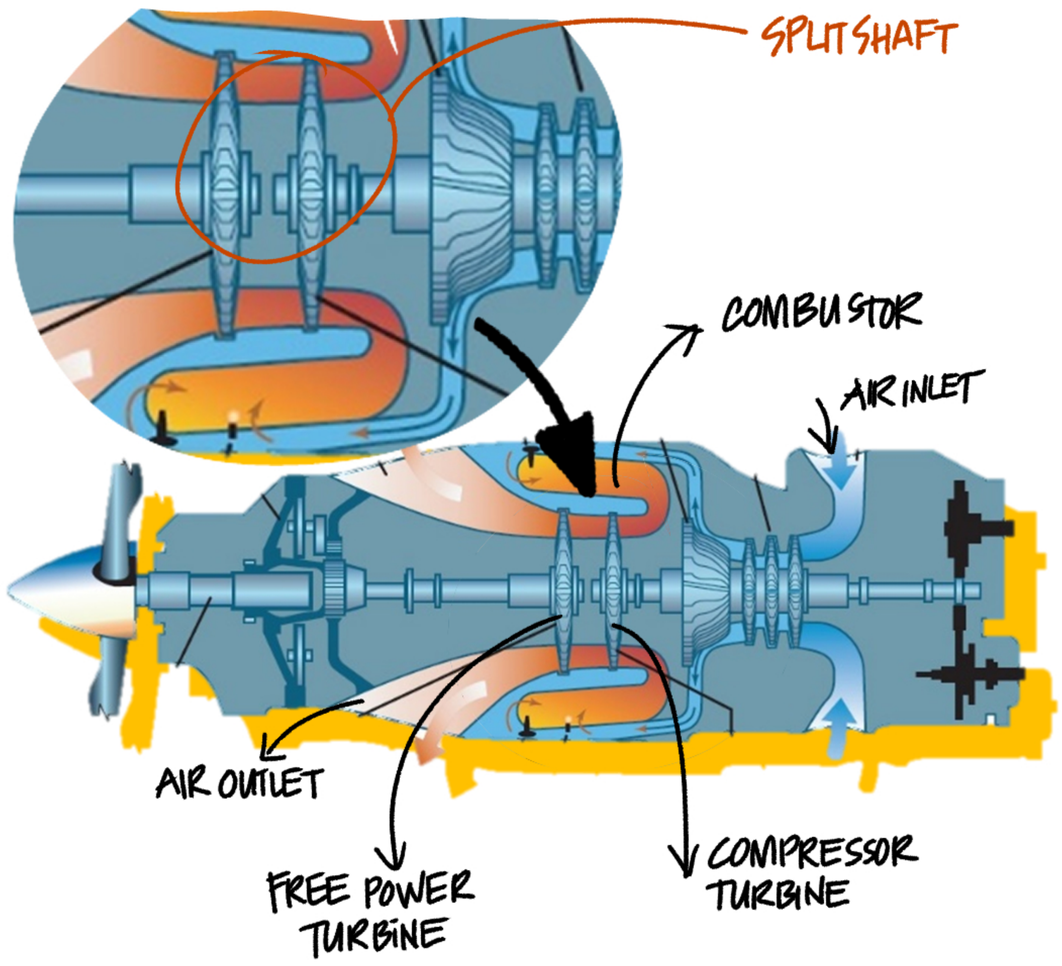
– IS THE **REMOVAL OF HEAT FROM COMPRESSED AIR** BETWEEN STAGES OF COMPRESSION.

REHEATING

– IS THE **INCREASE IN TEMPERATURE OF PARTIALLY EXPANDED GAS** BY BURNING MORE FUEL IN IT.

EFFECTS OF GAS TURBINE IMPROVEMENTS

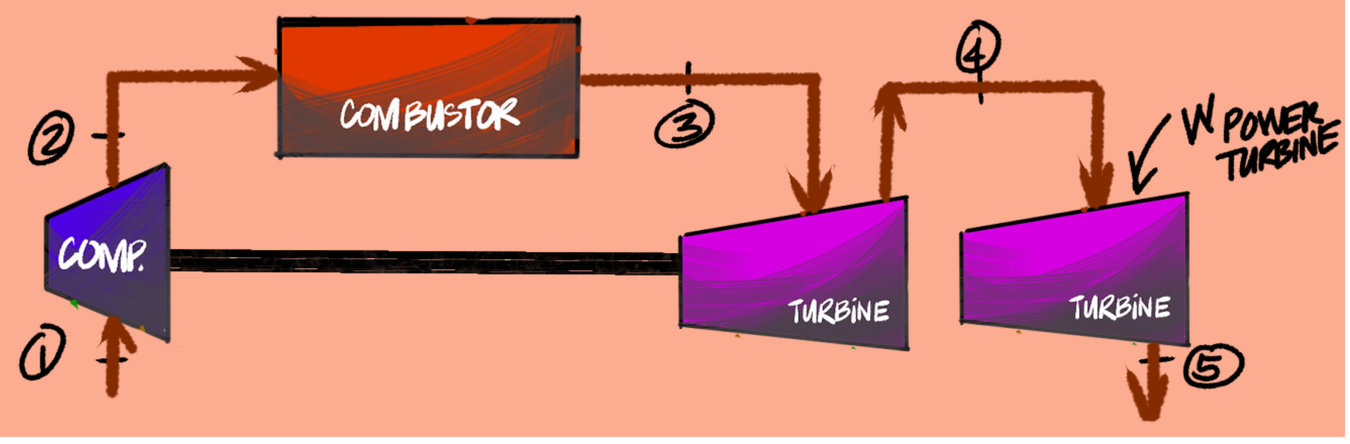
MODIFICATIONS	COMPRESSOR WORK	BACK WORK RATIO	THERMAL EFFICIENCY
MULTISTAGE COMPRESSION	DECREASE	DECREASE	DECREASE
REHEAT	STAYS THE SAME	DECREASE	DECREASE
MULTISTAGE COMPRESSION WITH REHEATING	DECREASE	DECREASE	DECREASE
MULTISTAGE COMPRESSION WITH REHEATING AND REGENERATION	DECREASE	DECREASE	INCREASE



TEMPERATURE ENTERING THE EXPANDER	1200°C - 1290°C
EXHAUST TEMPERATURE	540°C - 590°C
EXHAUST FLOWRATE IN MODERN HEAVY DUTY TURBINES PER **100** MV	240 - 250 kg/s
TURBINE POWER USED TO DRIVE THE HIGH EFFICIENCY COMPRESSOR	50-75%
TEMPERATURE OF THE AIR ENTERING THE TURBINE	650 - 1000°C
TEMPERATURE OF THE **AIR ENTERING THE TURBINE** (MAXIMUM TEMPERATURE **BY METALLURGICAL REASONS**)	1700°C
THERMAL EFFICIENCY OF EXISTING **HEAVY-DUTY COMBUSTION TURBINES** IN SIMPLE CYCLE	34 - 36%
THERMAL EFFICIENCY AERODERIVATIVE TURBINES	42%
BACK WORK RATIO	50 - 75%
ACTUAL **REGENERATION EFFICIENCY**	< 75%

SPLIT SHAFT

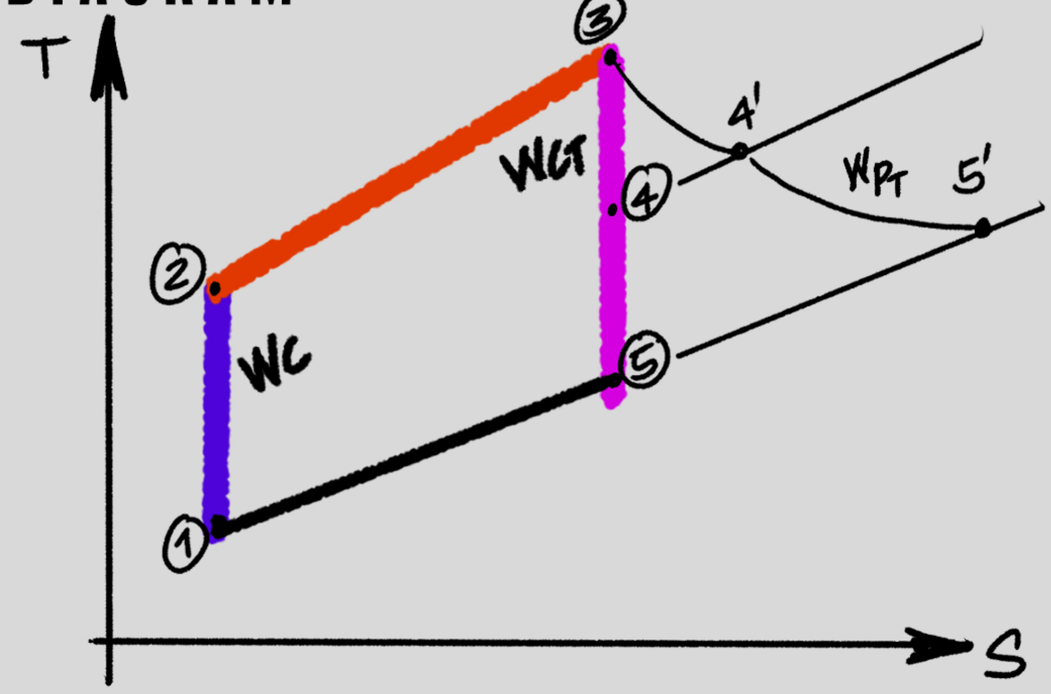
SCHEMATIC DIAGRAM



PROCESS

1-2	ISENTROPIC WORK
2-3	ISOBARIC HEATING
3-4	ISENTROPIC WORK (WC)
4-5	ISENTROPIC WORK (WP)

DIAGRAM



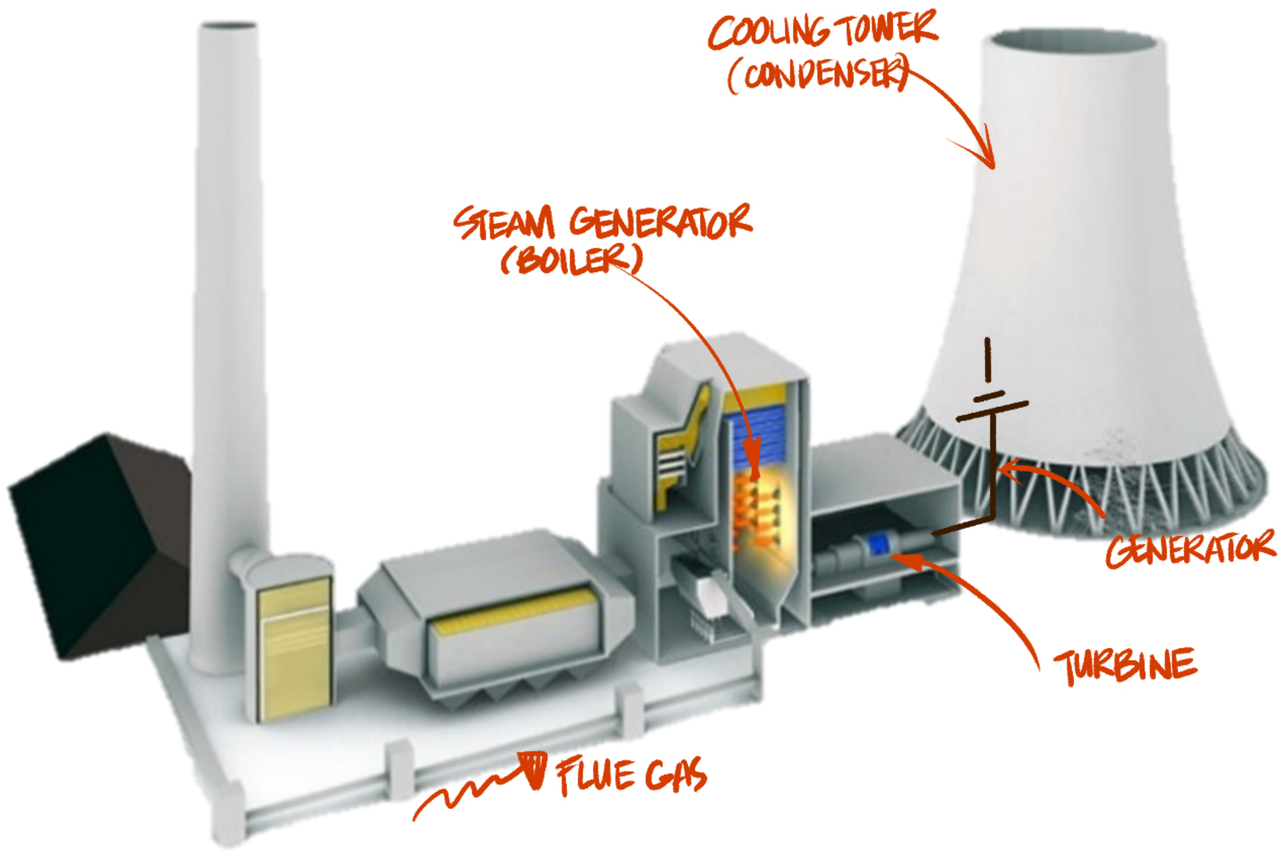
NOTE:

$$W_{CT} = W_C$$

☑ FOR EFFICIENCY:

$$e = \frac{W_{NET}}{Q_A} = \frac{W_{PT}}{Q_A} \rightsquigarrow \text{FREE TURBINE}$$

STEAM POWER PLANT



STEAM POWER PLANT

- A STEAM POWER PLANT CONSISTS OF A **BOILER, STEAM TURBINE AND GENERATOR, AND OTHER AUXILIARIES**. THE BOILER GENERATES STEAM AT HIGH PRESSURE AND HIGH TEMPERATURE.
- THE STEAM TURBINE CONVERTS THE HEAT ENERGY OF STEAM INTO MECHANICAL ENERGY. THE GENERATOR THEN CONVERTS THE MECHANICAL ENERGY INTO ELECTRIC POWER.

BASIC ELEMENTS OF PLANT DESIGN

STEAM GENERATOR	- COMBINATION OF APPARATUS FOR PRODUCING, FURNISHING, OR RECOVERING HEAT, TOGETHER WITH APPARATUS FOR TRANSFERRING TO A WORKING FLUID THE HEAT THUS MADE AVAILABLE. - IT INDICATES THE FURNACE, BOILER, WATERWALLS, WATER FLOOR, WATER SCREEN, SUPERHEATER, REHEATER, ECONOMIZER, AIR PREHEATER, AND FUEL-BURNING EQUIPMENT. - **THE TERM BOILER HAS BEEN USED FOR SUCH A LONG PERIOD OF TIME THAT THE TWO TERMS ARE USED INTERCHANGEABLY.**
STEAM TURBINE	- IT IS A PRACTICAL POWER SOURCE WHEN BUILT IN AS SMALL AS **5 HP** OR AS LARGE AS **100,000**. IT IS RELATIVELY QUIET AND SMOOTH IN OPERATION.
CONDENSER	- A HEAT EXCHANGER WHERE STEAM ENTERS THE TOP AND THE CONDENSATE IS COLLECTED IN THE HOT WELL AT THE BOTTOM WHILE COOLING WATER FLOWS THROUGH THE TUBES.
BOILER FEED PUMP OR FEEDWWATER PUMPS	- ITS FUNCTION IS TO **INCREASE THE PRESSURE** EXISTING ON A LIQUID AN INCREMENT SUFFICIENT TO THE REQUIRED SERVICE.

RANKINE CYCLE

– IS THE **IDEAL STEAM POWER** CYCLE. THIS IDEAL PLANT CONSIST OF A STEAM GENERATOR WHICH RECEIVES FEEDWATER UNDER PRESSURE FROM A PUMP, A PRIME MOVER IN WHICH TO OBTAIN THE WORKING EXPANSION, AND A CONDENSER TO REDUCE THE EXHAUST STEAM TO LIQUID, READY FOR PUMPING.

QUALITY:

FROM ① – ② : CONSTANT S

$S_1 = S_2$ (ISENTROPIC)

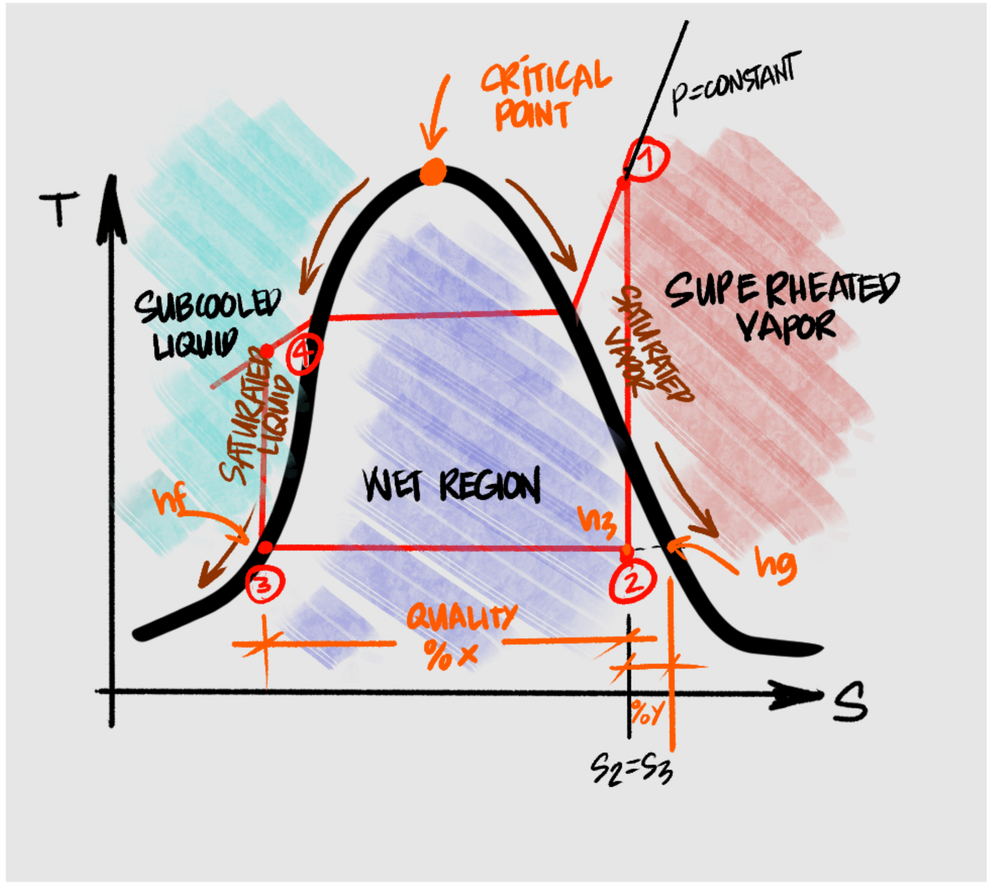
$S_2 = S_{f2} + x(S_{fg_2})$

$$x = \frac{S_x - S_f}{S_g - S_f} = \frac{h_x - h_f}{h_g - h_f}$$

BUT: $S_g - S_f = S_{fg}$

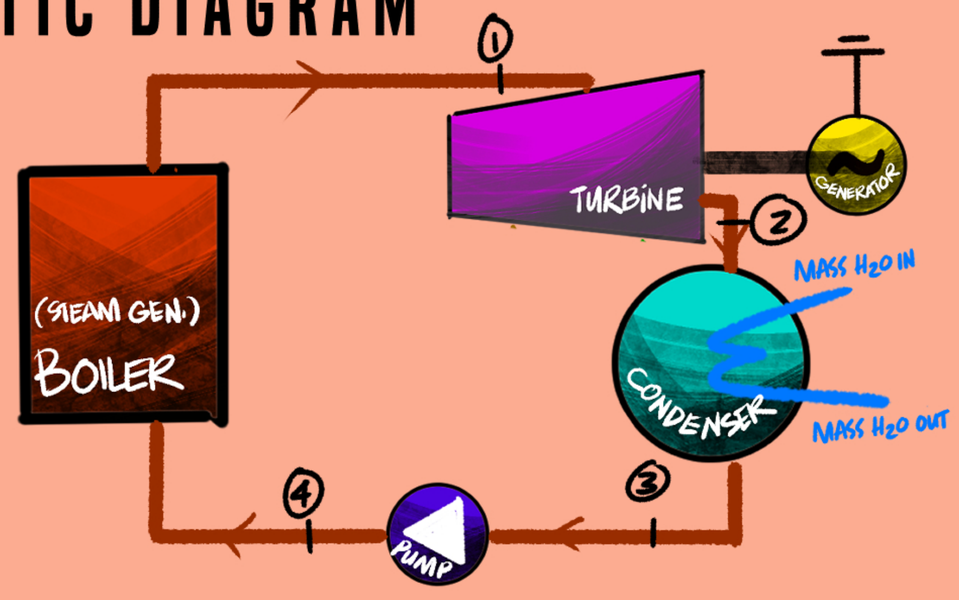
THUS;

$$h_2 = h_{f_2} + x h_{fg_2}$$



RANKINE CYCLE (IDEAL AND ACTUAL)

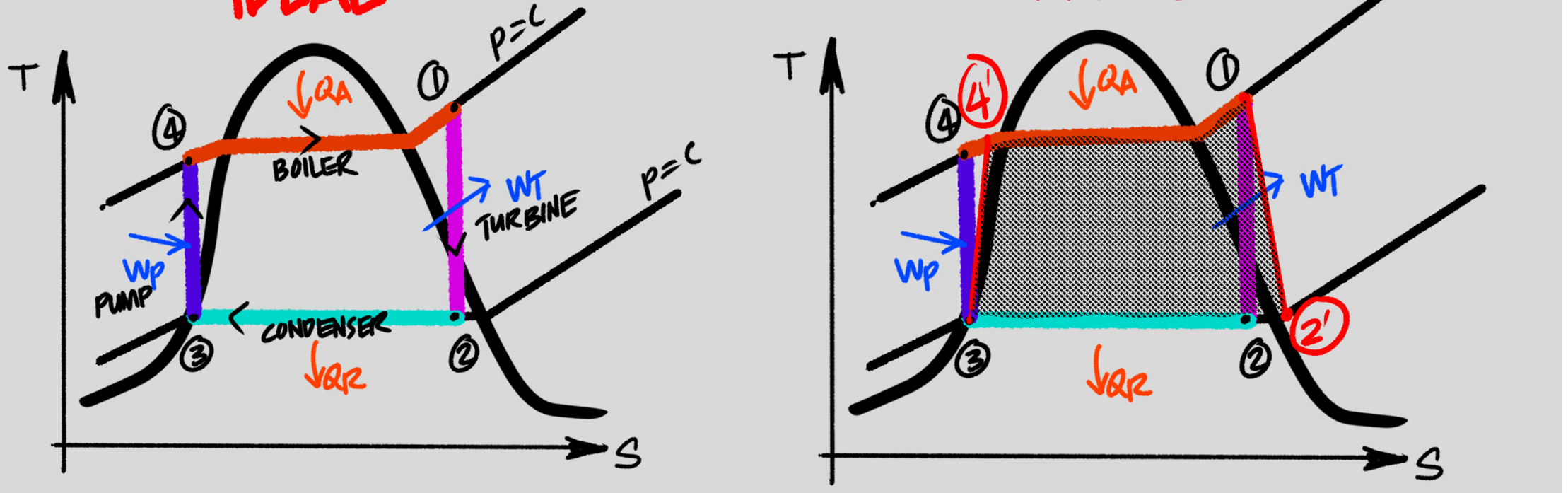
SCHEMATIC DIAGRAM



PROCESS

1-2	ISENTROPIC EXPANSION
2-3	ISOBARIC HEAT REJ.
3-4	ADIABATIC PUMPING
4-1	ISOBARIC HEAT ADD.

DIAGRAM



COMPUTATION

HEAT ADDED IN THE BOILER

$$Q_A = m(h_1 - h_4)$$

HEAT REJECTED IN THE CONDENSER

$$Q_R = m(h_2 - h_3)$$

TURBINE WORK

$$W_T = m(h_1 - h_2)$$

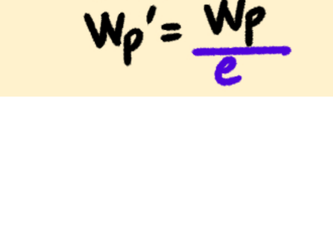
PUMP WORK

$$W_p = m(h_4 - h_3) \quad | \quad \dot{W}_p = v_3(P_4 - P_3)$$

WORK NET

$$W_{NET} = Q_A - Q_R = W_T - W_p$$

ALSO;



$$W_T = m[(h_1 - h_2) + \Delta KE]$$

$$e_{th} = \frac{W_{NET}}{Q_A} = \frac{(h_1 - h_2) - W_p}{(h_1 - h_3) - W_p}$$

WHERE:

$Q_A = h_1 - h_4$;

$h_4 = h_3 + W_p$

$Q_A = h_1 - (h_3 + W_p)$

!! EFFICIENCIES !!

PRODUCE POWER

TURBINE

- WHENER AN EQUIPMENT PRODUCES POWER; MULTIPLY!!

$W_T' = W_T \times e$

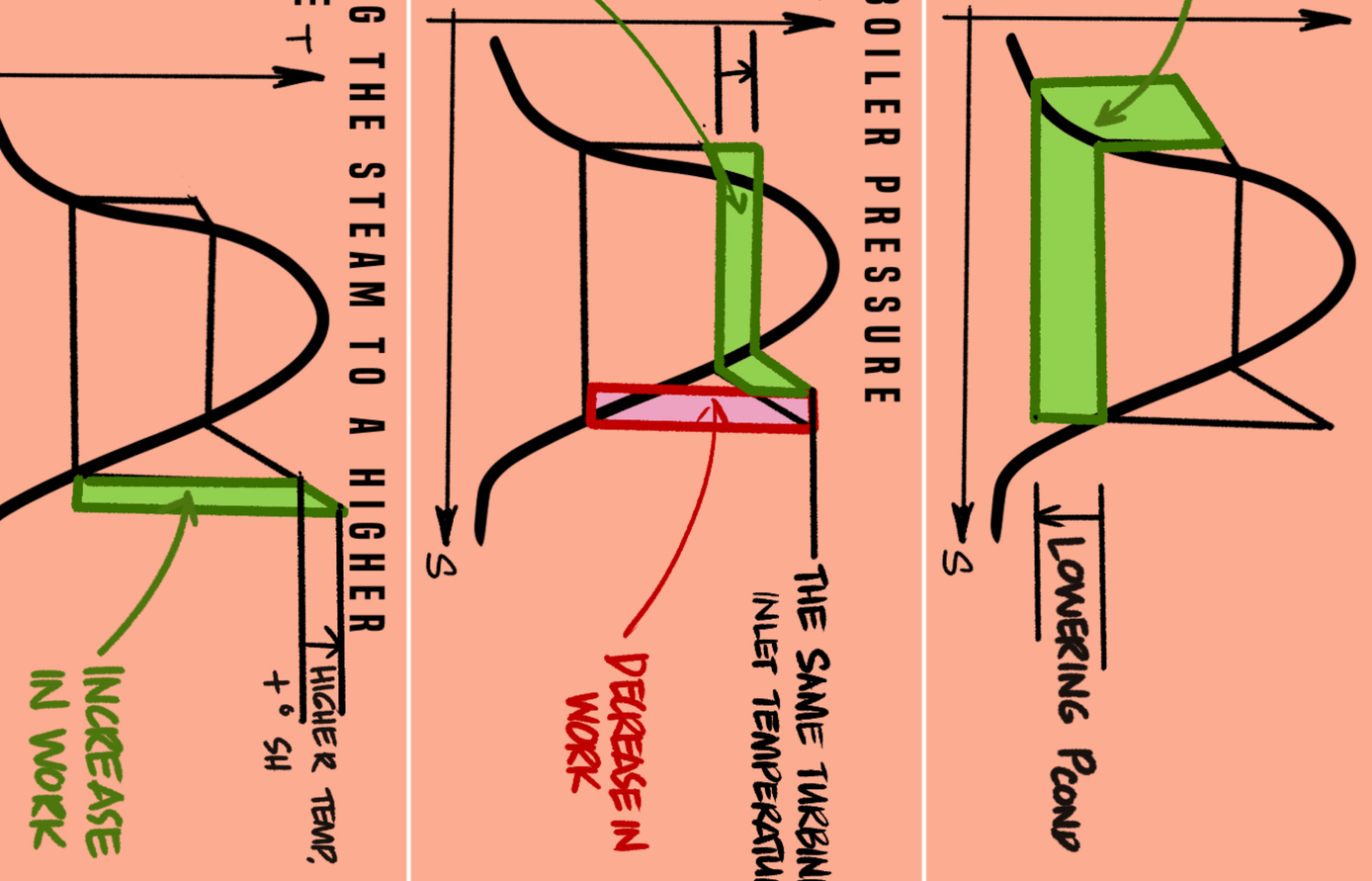
PUMP (SAME GOES WITH: FANS, BLOWERS, COMPRESSORS)

- WHENEVER AN EQUIPMENT CONSUMES POWER; DIVIDE!!

$W_p' = \frac{W_p}{e}$

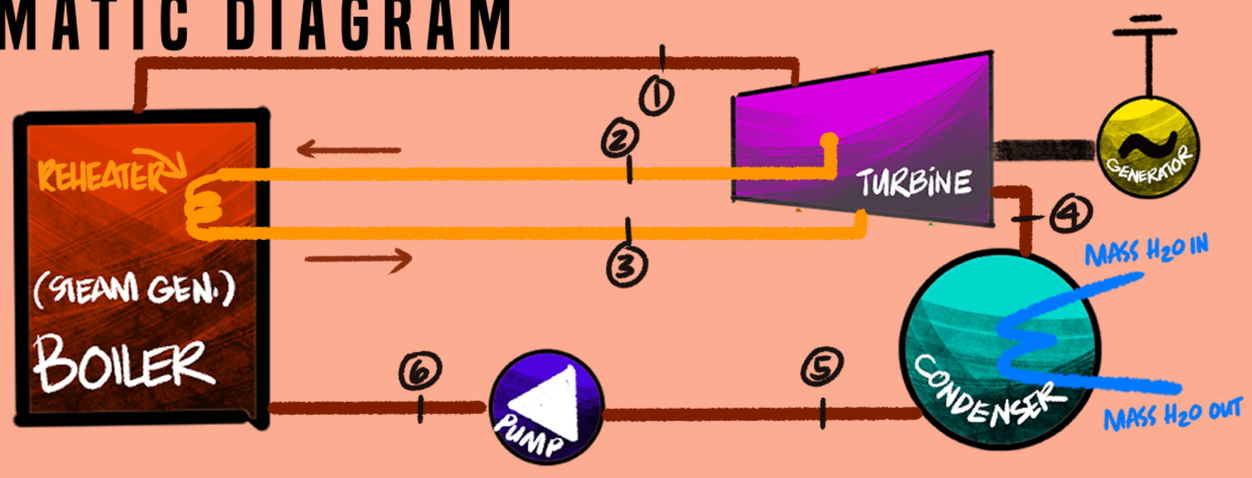
CONSUMES POWER

METHODS OF IMPROVING THE EFFICIENCY OF RANKINE CYCLE

LOWERING CONDENSER PRESSURE	INCREASING BOILER PRESSURE	SUPERHEATING THE STEAM TO A HIGHER TEMPERATURE	REHEATING THE STEAM	REGENERATION	IMPROVEMENT
					
DECREASE	REMAINS CONSTANT	REMAINS CONSTANT	INCREASE	INCREASE	PUMP WORK
DECREASE	INCREASE	INCREASE	INCREASE	INCREASE	TURBINE WORK
DECREASE	INCREASE	INCREASE	DECREASE	INCREASE	HEAT ADDED
DECREASE	INCREASE	INCREASE	DECREASE	DECREASE	HEAT REJECTED
INCREASE	INCREASE	INCREASE	INCREASE	INCREASE	CYCLE EFFICIENCY
REMAINS CONSTANT	DECREASE	DECREASE	INCREASE	INCREASE	MOISTURE CONTENT

REHEAT CYCLE

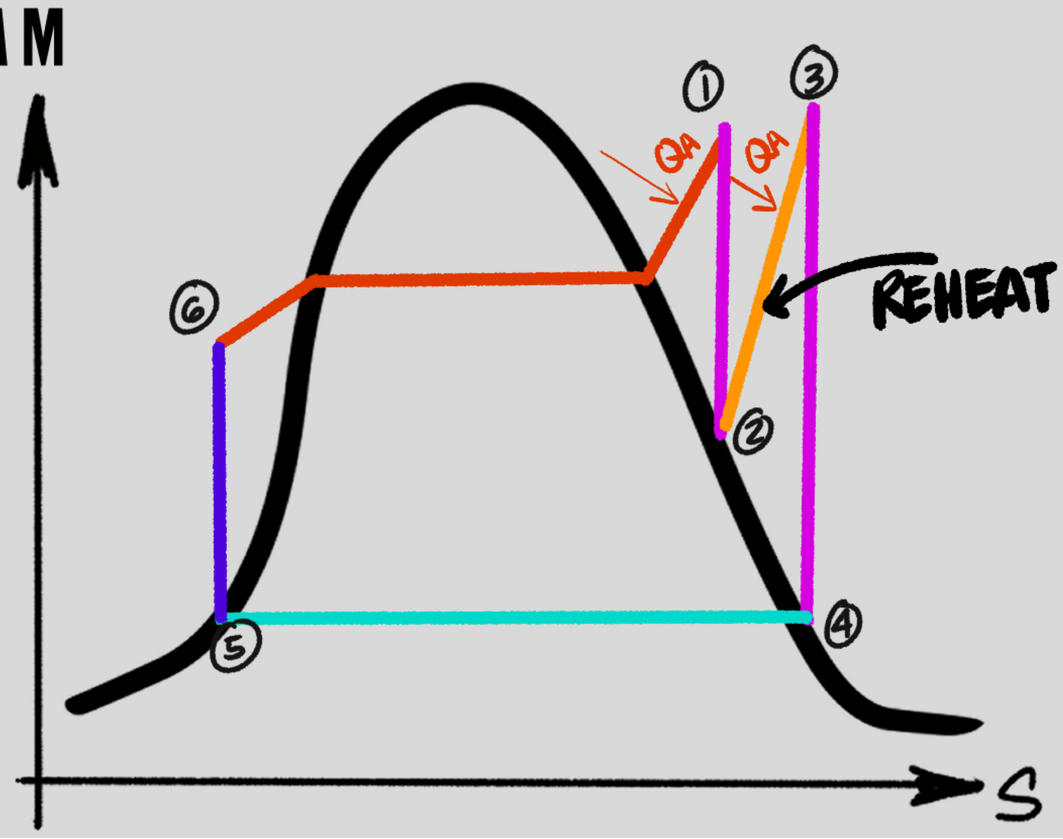
SCHEMATIC DIAGRAM



PROCESS

1-2	ISENTROPIC EXPANSION
2-3	ISOBARIC REHEATING
3-4	ISENTROPIC EXPANSION
4-5	ISOBARIC HEAT REJ.
5-6	ADIABATIC PUMPING
6-1	ISOBARIC HEAT ADD.

DIAGRAM



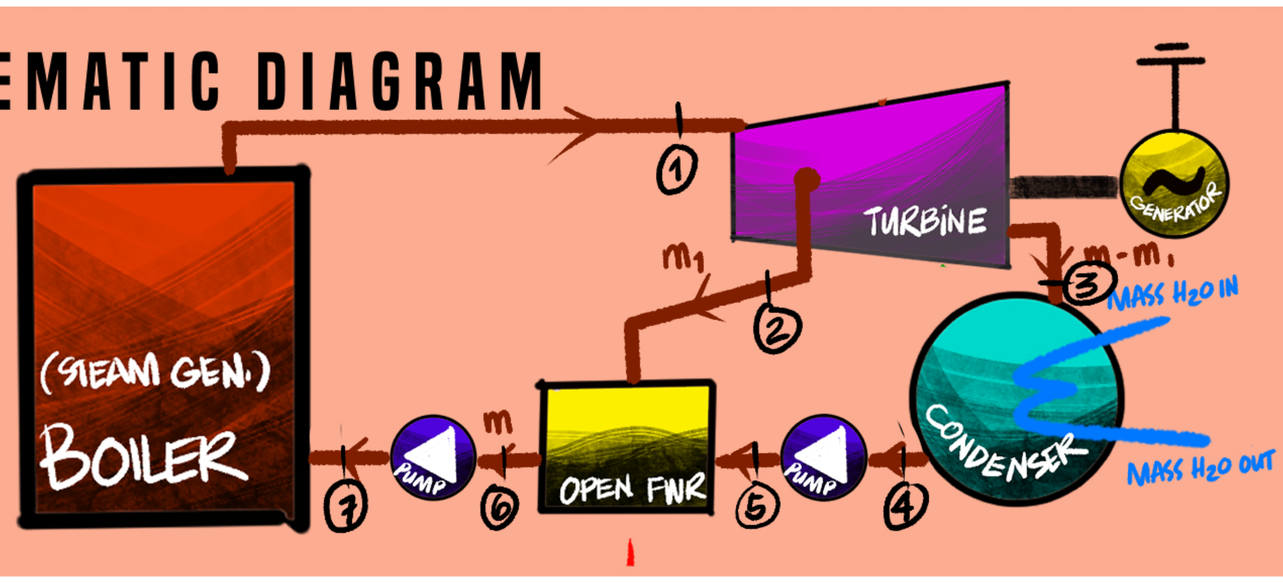
$$Q_A = m[(h_1 - h_6) + (h_3 - h_2)]$$

BOILER ← → REHEATER

$$W_T = m[(h_1 - h_2) + (h_3 - h_4)]$$

REGENERATIVE CYCLE

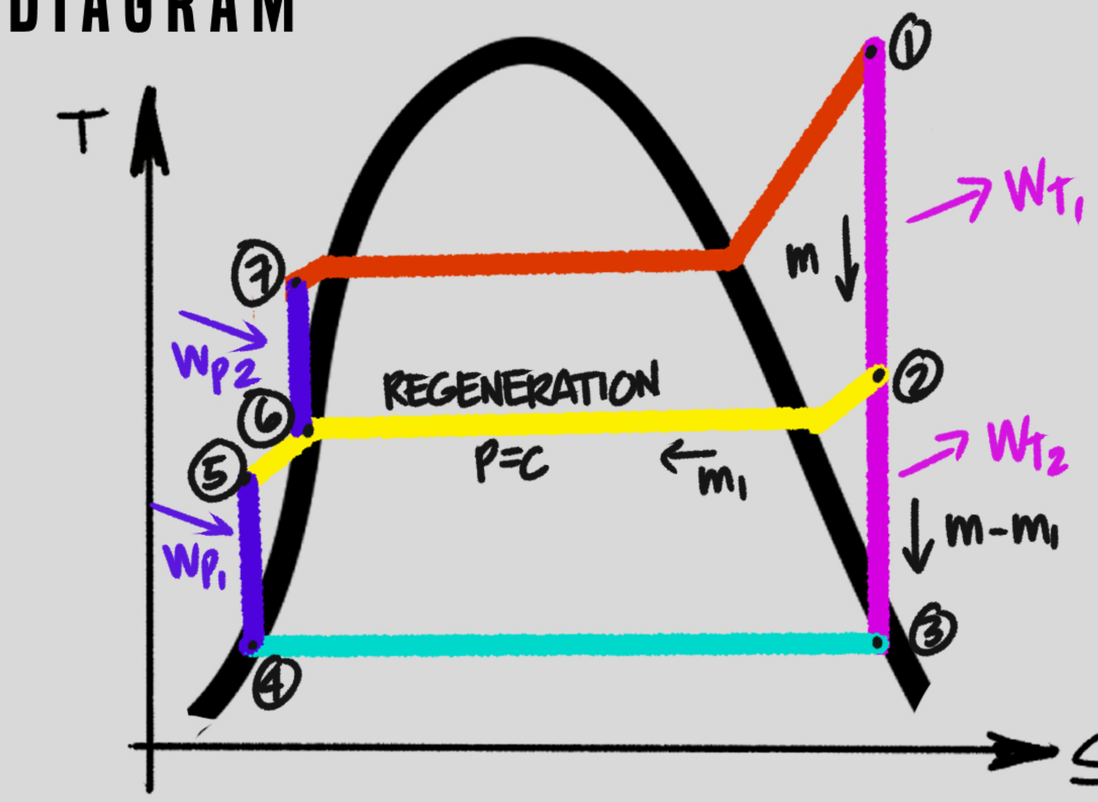
SCHEMATIC DIAGRAM



PROCESS

2-6	CONSTANT PRESSURE HEAT REJECTION IN REHEATER
4-5	ADIABATIC PUMPING (1ST STAGE)
6-7	ADIABATIC PUMPING (2ND STAGE)

DIAGRAM



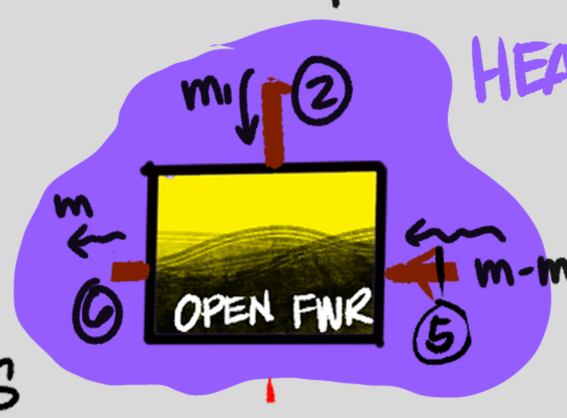
$$Q_A = m(h_1 - h_7)$$

$$W_T = W_{T1} + W_{T2}$$

$$W_T = m(h_1 - h_2) + (m - m_1)(h_2 - h_3)$$

$$W_p = W_{p1} + W_{p2}$$

$$W_p = (m - m_1)(h_5 - h_4) + m(h_7 - h_6)$$



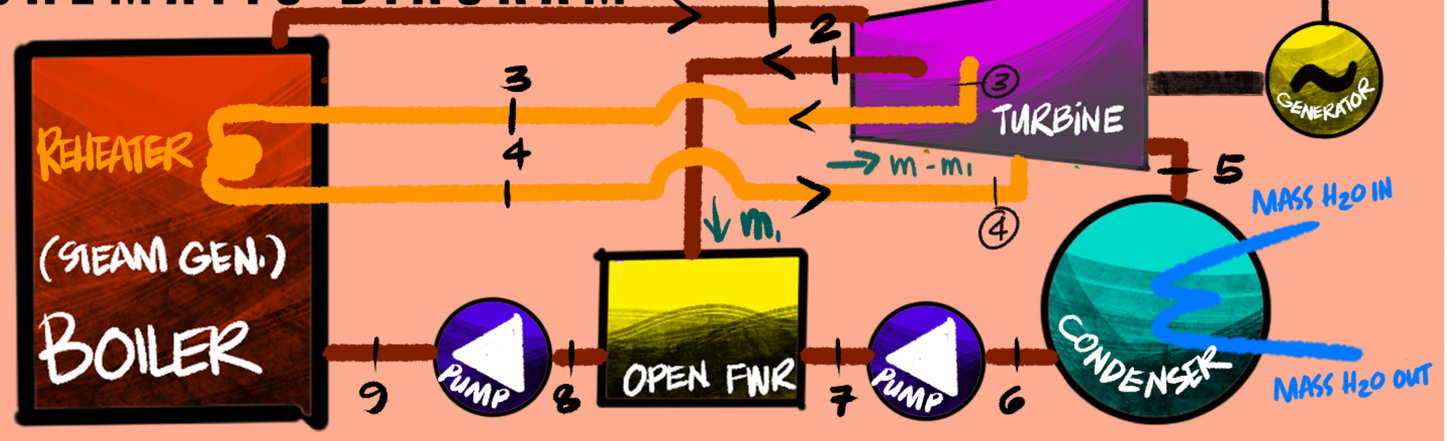
HEAT BALANCE:

$$m_1 h_2 + (m - m_1) h_5 = m h_6$$

$$m_1 = \frac{h_6 - h_5}{h_2 - h_5}$$

REHEAT-REGENERATIVE CYLCE

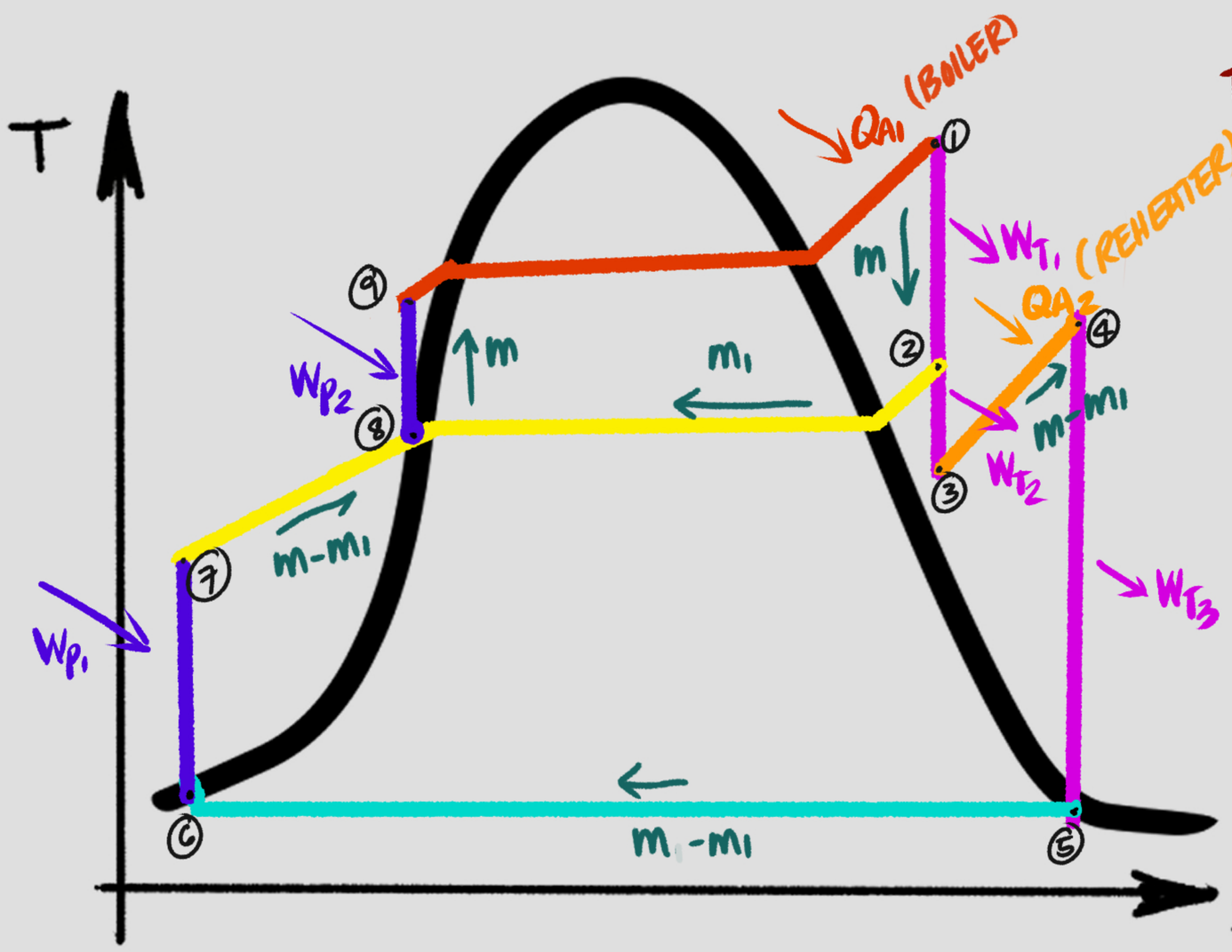
SCHEMATIC DIAGRAM



PROCESS

1-2	PARTIAL ISENTROPIC EXP.
2-3	INTERMEDIATE PARTIAL ISEN. EXP.
2-8	ISOBARIC HEAT REJ. IN HEATER
7-8	ISOBARIC HEAT ADD. IN HEATER
3-4	ISOBARIC RESUPERHEATING IN THE REHEATER
4-5	COMPLETE ISENTROPIC EXPANSION

DIAGRAM



TOTAL HEAT ADDED

$$Q_A = Q_{A1} + Q_{A2}$$
$$= Q_{BOILER} + Q_{REHEATER}$$

- $Q_A = m(h_1 - h_9) + (m - m_1)(h_4 - h_3)$

TOTAL TURBINE WORK

$$W_T = W_{T1} + W_{T2} + W_{T3}$$

- $W_T = m(h_1 - h_2) + (m - m_1)(h_2 - h_3) + (m - m_1)(h_4 - h_5)$

TOTAL PUMP WORK

$$W_p = W_{p1} + W_{p2}$$

- $W_p = (m - m_1)(h_7 - h_6) + m(h_9 - h_8)$
- $W_p = (m - m_1)v_{f6}(P_7 - P_6) + m v_{f8}(P_9 - P_8)$
- $W_p \simeq v_{f6}(P_9 - P_6)$

EFFICIENCY:

$$e = \frac{W_{NET}}{Q_A} = \frac{W_{T\,TOTAL} - W_{P\,TOTAL}}{Q_{A\,TOT}}$$

ADDITIONAL:

$$E = \frac{Q}{Q + Q_S}$$

$Q = \Delta h$

$Q_S = T_{atm}(\Delta S)$

REGENERATIVE CYCLE

REGENERATION

- IS A PROCESS WHERE HEAT IS EXTRACTED BETWEEN THE TURBINE STAGES AND USED TO HEAT WATER COMING FROM THE CONDENSER THUS INCREASING THE TEMPERATURE OF FEEDWATER TO THE BOILER.

TWO TYPES:

1. OPEN FEEDWATER HEATER

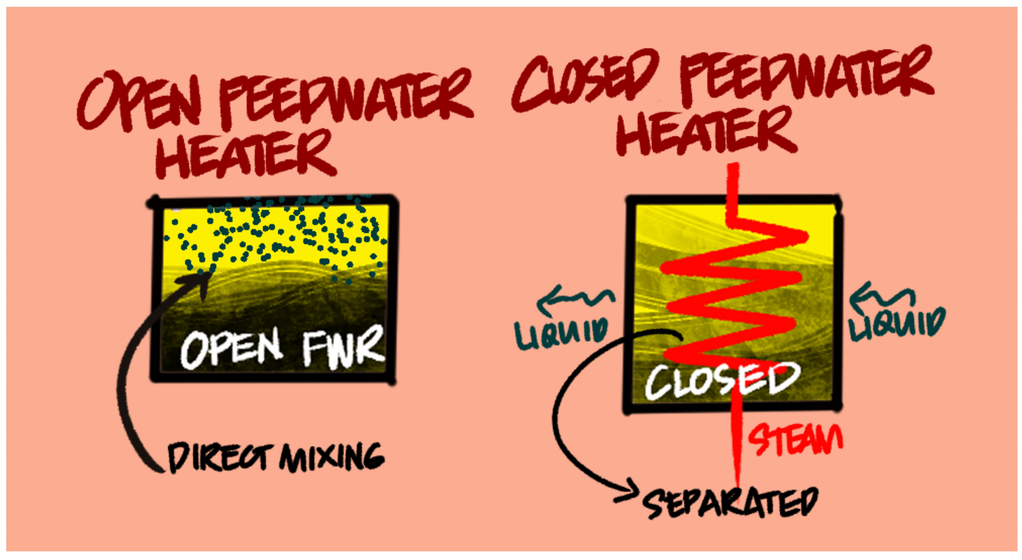
- DIRECT CONTACT HEATER AND THE STEAM AND WATER MIX

1. CLOSED FEEDWATER HEATER

- HEAT EXCHANGER THAT CAN OPERATE AT EITHER HIGH OR LOW PRESSURE AND THERE IS NO MIXING OF THE WATER AND STEAM IN THE HEATER

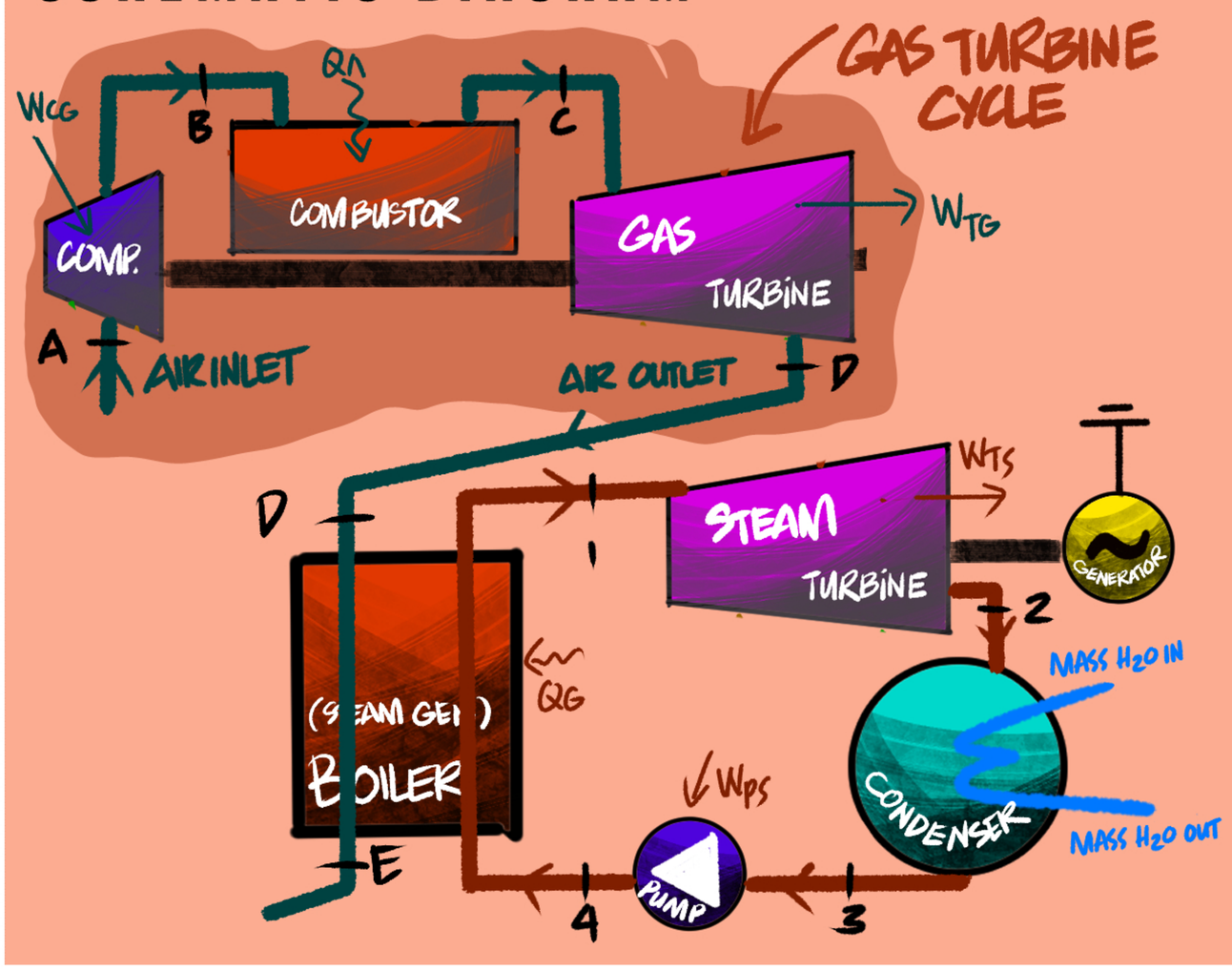
FEEDWATER HEATER

- IS A HEATING SYSTEM THAT USES STEAM TO INCREASE THE TEMPERATURE ENTERING THE BOILER.



COMBINED GAS TURBINE – STEAM CYCLE

SCHEMATIC DIAGRAM



IS USED TO TRANSFER HEAT CARRIED BY THE FLUE GAS IN THE GAS TURBINE CYCLE (EXHAUSE) TO THE FEEDWATER IN THE STEAM CYCLE; THE HEAT EXCHANGER PERFORMS THE FUNCTION OF A BOILER.

THERMAL EFFICIENCY OF THE COMBINED CYCLE:

$$e_C = \frac{W_{NETG} + W_{NETS}}{Q_A} = \frac{(W_{TG} - W_{CG}) + (W_{TS} - W_{PS})}{m_{AIR} c_p (T_C - T_B)}$$

HEAT GAINED:

$$Q_G = m_{fw}(h_1 - h_4) = m_S(h_1 - h_4)$$

$$m_{fw} = m_S$$

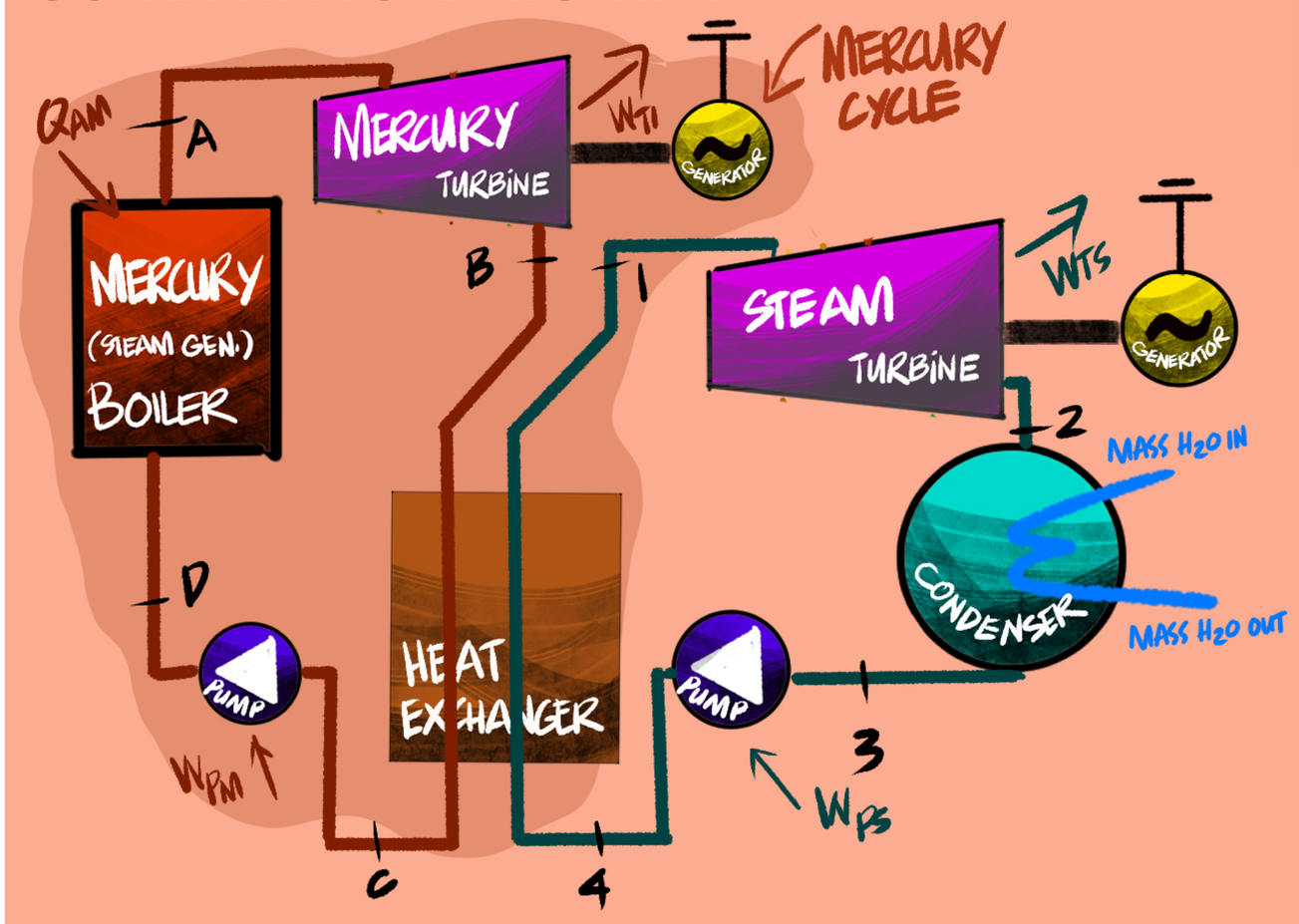
ENERGY BALANCE:

$$m_S(h_1 - h_4) = m_{AIR} c_p (T_E - T_D)$$

$$m_S = \frac{m_{AIR} c_p (T_E - T_D)}{h_1 - h_4}$$

BINARY MERCURY – STEAM POWER PLANT

SCHEMATIC DIAGRAM



IS USED TO TRANSFER HEAT CARRIED BY THE MERCURY IN THE MERCURY VAPOR CYCLE TO THE FEEDWATER IN THE STEAM CYCLE; THE HEAT EXCHANGER PERFORMS THE FUNCTION OF A BOILER.

THERMAL EFFICIENCY OF THE BINARY CYCLE:

$$e = \frac{W_{NET}}{Q_A} = \frac{W_T - W_P}{Q_A}$$

OVERALL TURBINE WORK:

$$W_T = W_{TM} + W_{TS} = m_M(h_A - h_B) + m_S(h_1 - h_2)$$

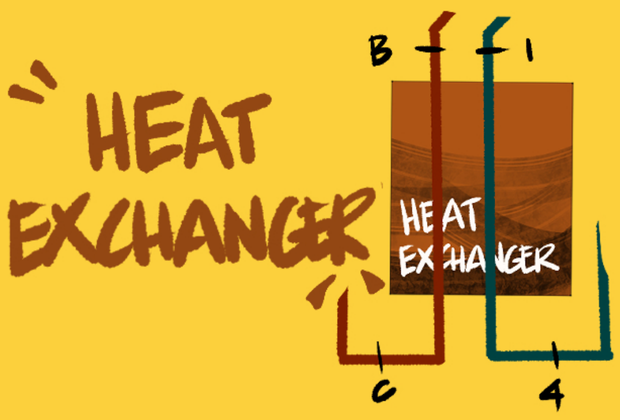
OVERALL PUMP WORK:

$$W_P = W_{PM} + W_{PS} = m_M(h_D - h_C) + m_S(h_4 - h_3)$$

HEAT ADDED:

$$Q_A = m_M(h_A - h_D)$$

ENERGY BALANCE:



HEAT LOSS BY MERCURY = HEAT GAINED BY WATER

$$m_M(h_B - h_C) = m_{fw}(h_1 - h_4)$$

$$m_{fw} = m_S$$

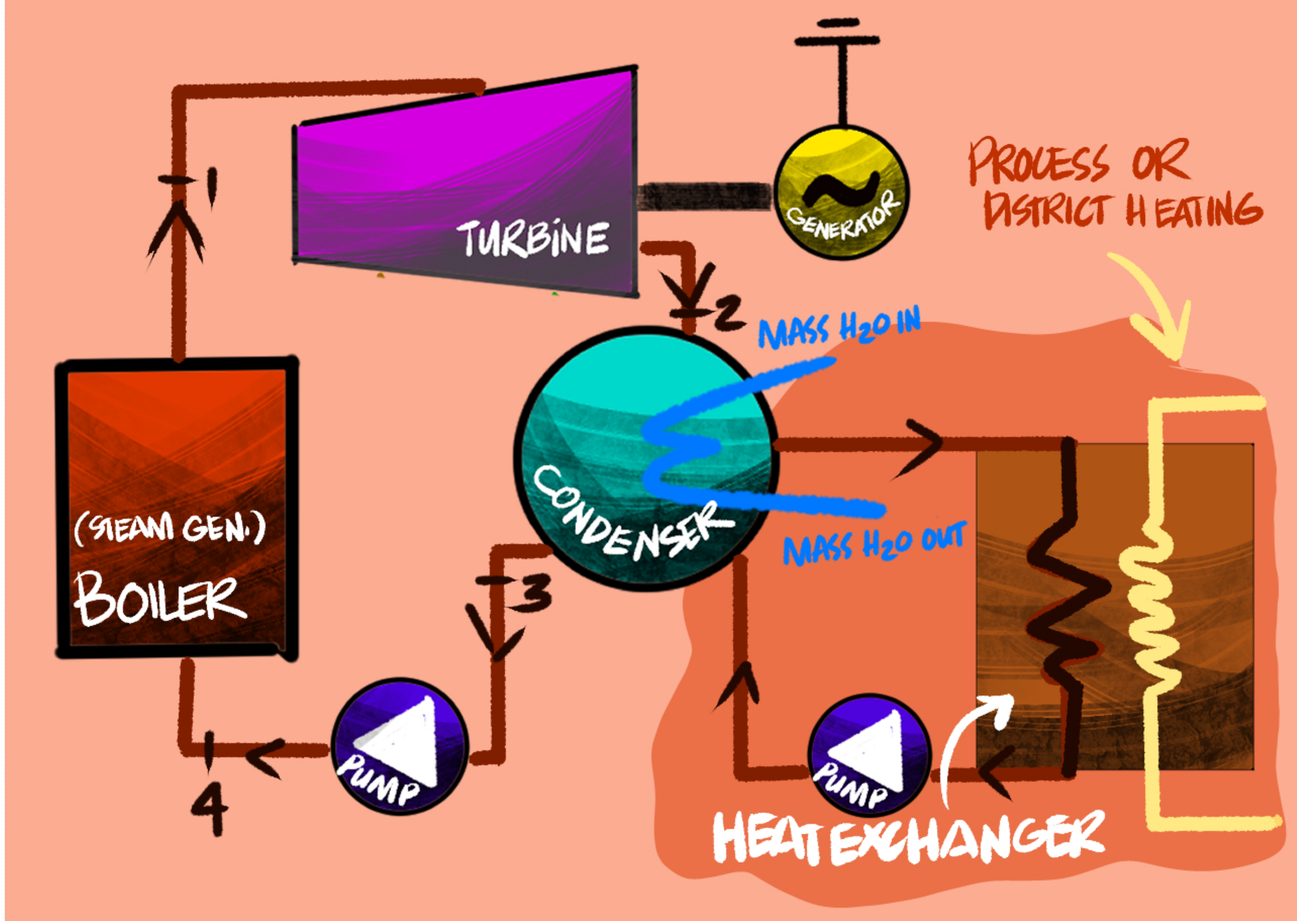
$$m_M = \frac{m_{fw}(h_1 - h_4)}{h_B - h_C}$$

m_S = STEAM MASS FLOW RATE

m_{fw} = FEEDWATER MASS FLOW RATE

m_M = MERCURY FLOW RATE

COGENERATION STEAM POWER PLANT



- COGENERATION IS THE PRODUCTION OF MORE THAN ONE USEFUL FORM OF ENERGY (SUCH AS PROCESS OF HEAT AND ELECTRIC POWER) FROM THE SAME ENERGY SOURCE.
- COMMON EXAMPLES OF COGENERATION APPLICATIONS INCLUDE PULP AND PAPER MILLS, STEEL MILLS, FOOD AND CHEMICAL PROCESSING PLANTS, AND DISTRICT HEATING (DH) APPLICATIONS.

COGENERATIVE EFFICIENCY

$$e_c = \frac{W_T + Q_R}{Q_A}$$

→ HEAT REJECTED BY CONDENSER IS NOW USEFUL!

$$e_c = 1 - \frac{Q_R}{Q_A}$$

ADDITIONAL INFORMATION

- RANKINE CYCLE POWER CONVERTS **26%** OF THE HEAT IT RECEIVES IN THE BOILER TO NET WORK.
- ONLY **0.4%** OF THE TURBINE WORK IS REQUIRED TO OPERATE THE PUMP
- THE HIGHEST STEAM TEMPERATURE ALLOWED AT THE TURBINE INLET IS ABOUT **620 DEG. CELCIUS**. CERAMICS ARE VERY PROMISING IN THIS REGARD.
- IN A REHEAT CYCLE, THE OPTIMUM REHEAT PRESSURE IS ABOUT **¼ OF THE MAXIMUM CYCLE PRESSURE**
- A **TRAP** ALLOWS THE LIQUID TO BE THROTTLED TO A LOWER PRESSURE REGION BUT TRAPS THE VAPOR.
- BINARY CYCLE IS COMPOSED OF TWO SEPARATE CYCLES, ONE AT HIGH TEMPERATURES (**TOPPING CYCLE**) AND THE OTHER AT RELATIVE LOW TEMPERATURE
- COMBINED CYCLES HAVE A HIGHER THERMAL EFFICIENCY THAN THE STEAM/GAS TURBINE CYCLES.
- **STEAM IS NOT AN IDEAL GAS!**

STEAM GENERATOR

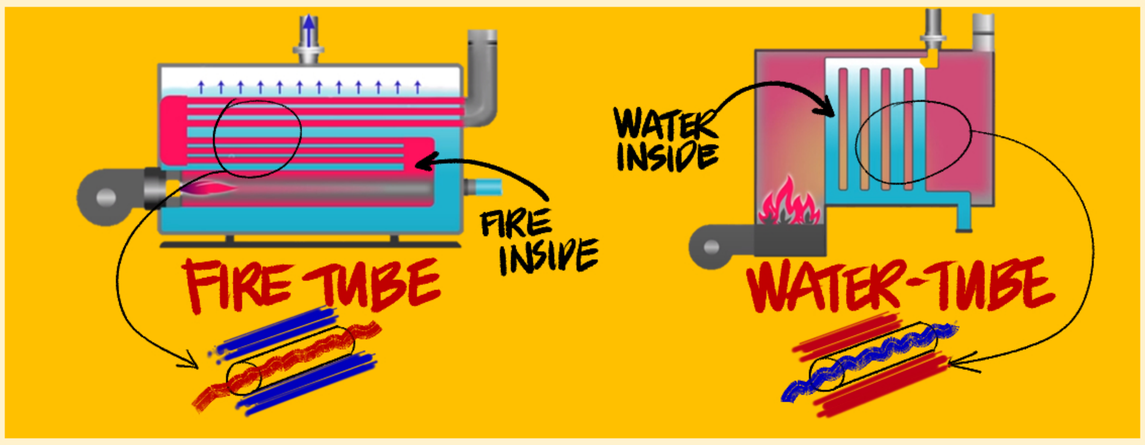
COMMONLY REFERRED TO AS **BOILER** – IS AN INTEGRATED ASSEMBLY OF SEVERAL ESSENTIAL COMPONENTS THE FUNCTION OF WHICH IS **TO PRODUCE STEAM AT A PREDETERMINED PRESSURE AND TEMPERATURE.**

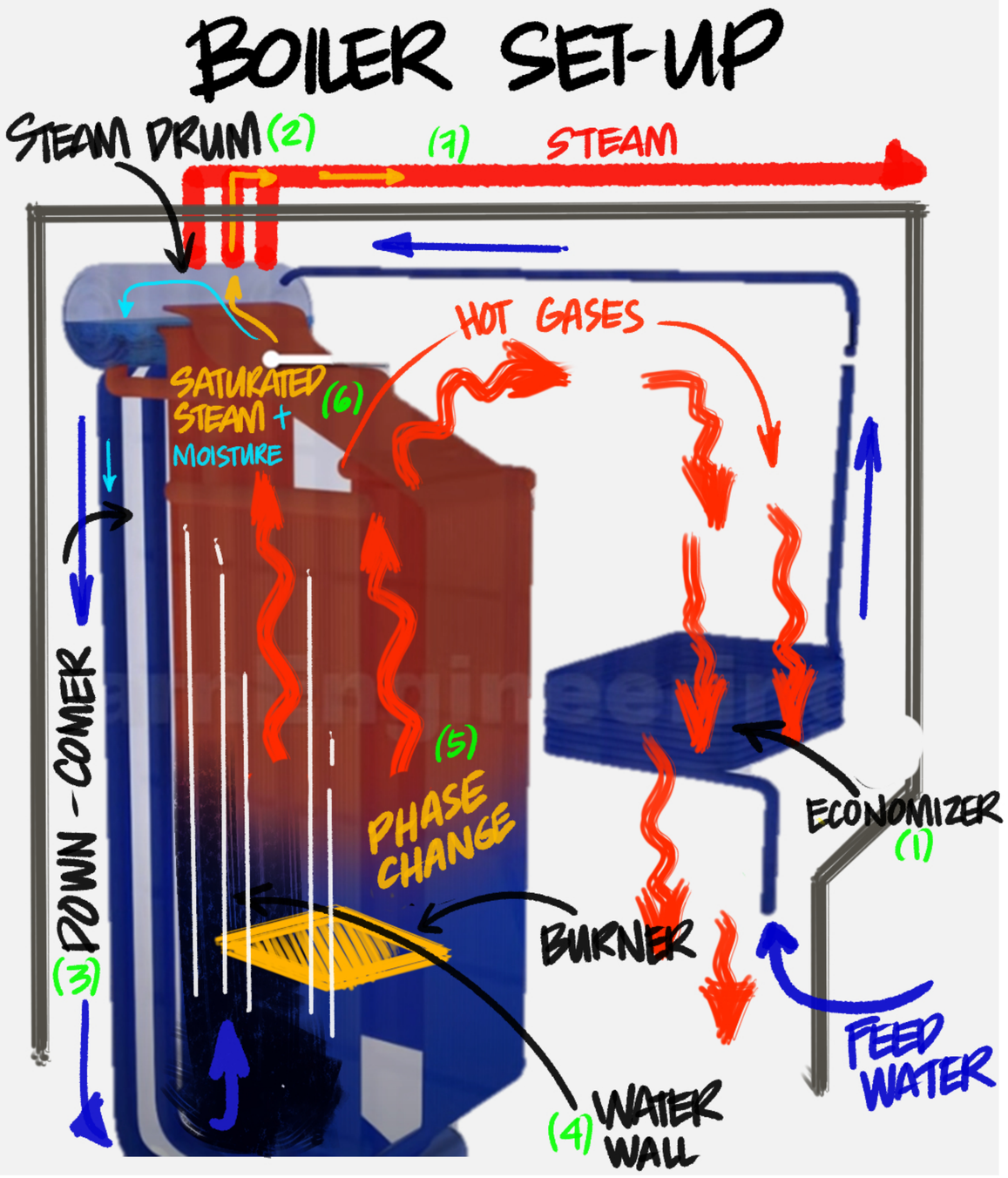
TYPES OF BOILERS

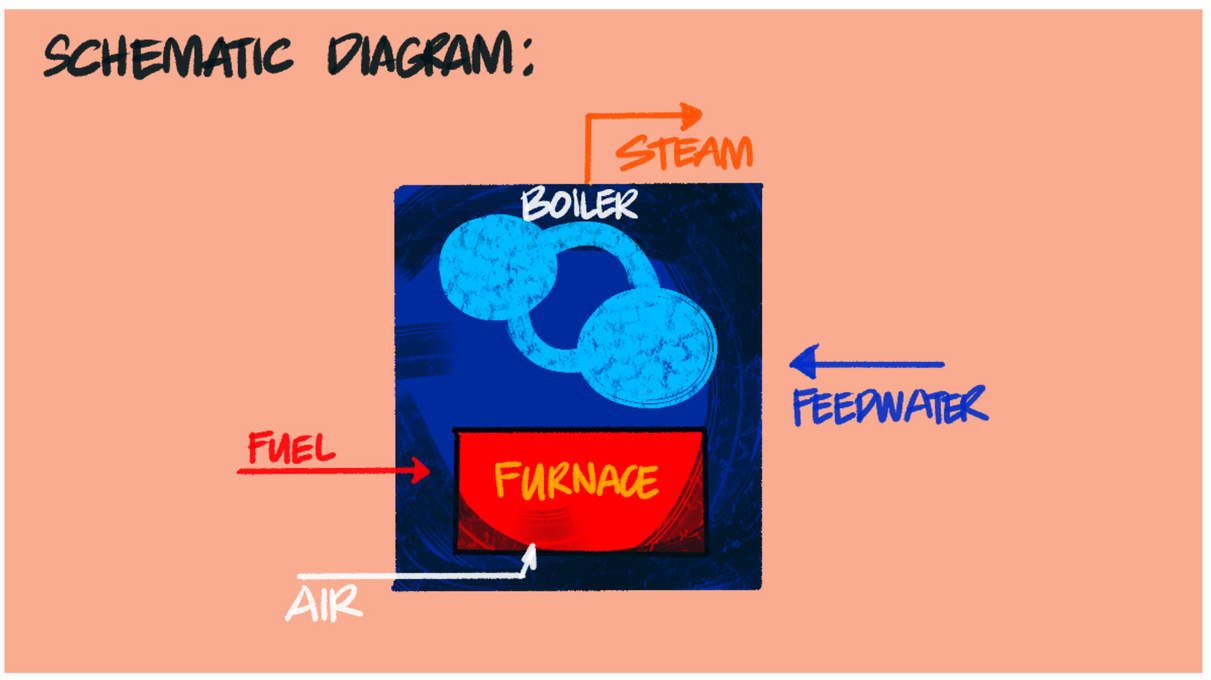
TYPE	DEFINITION
BOILER OR STEAM GENERATOR	A CLOSED VESSEL INTENDED FOR USE IN **HEATING WATER OR FOR APPLICATION OF HEAT TO GENERATE STEAM** OR OTHER VAPOR TO BE USED EXTERNALLY TO ITSELF.
UNFIRED PRESSURE BOILER	A VESSEL IN WHICH PRESSURE IS OBTAINED FROM AN **EXTERNAL SOURCE**, OR FROM AN **INDIRECT APPLICATION OF HEAT**
POWER BOILER	STEAM IS GENERATED AT A PRESSURE OF MORE THAN **1.055 KG/CM2 GAGE** BY THE **DIRECT** APPLICATION OF HEAT.
LOCOMOTIVE BOILER	MOUNTED ON A SELF-PROPELLED TRACK LOCOMOTIVE AND USED TO FURNISH MOTIVATING POWER FOR **TRAVELING ON RAILS.**
PORTABLE BOILER	AN INTERNALLY FIRED BOILER WHICH IS SELF-CONTAINED AND INTENDED FOR **TEMPORARY LOCATION.**
MINIATURE BOILER	MAX LIMIT: $d_i = 405\ mm$, $L = 1065\ mm$, $P = 7.03\ \frac{kg}{cm^2}$ WORKING PRESSURE
LOW PRESSURE	MAXIMUM: $P = 1.055\ \frac{kg}{cm^2}\ gage$, $T = 121°C$
MEDIUM PRESSURE	MAXIMUM: $P = 103.5\ MPa_{gage}$, $T = 130°C$
HOT WATER SUPPLY BOILER	FURNISHING HOT WATER TO BE USED EXTERNALLY TO ITSELF
SECOND HAND BOILER	A BOILER OR UNFIRED PRESSURE VESSEL WHERE **BOTH THE LOCATION AND OWNERSHIP HAVE BEEN CHANGED AFTER PRIMARY USE**
REINSTALLED BOILER	REMOVED FROM ITS ORIGINAL SETTING AND RE-ERECTED AT THE SAME LOCATION OR ERECTED AT A LOCATION **WITHOUT CHANGE OF OWNERSHIP.**
CONDEMNED BOILER	DECLARED UNSAFE TO OPERATE
OIL FIRED	USES **BUNKER C** AS FUEL

FIRE TUBE VS WATER TUBE???

- **FIRE TUBE** – PRODUCTS OF COMBUSTION INSIDE TUBE – WATER OUTSIDE THE TUBE (CHEAPEST)
- **WATER-TUBE** – WATER INSIDE THE TUBE – PRODUCTS OF COMBUSTION OUTSIDE THE TUBE.







PARTS OF STEAM GENERATOR

• PRESSURE PARTS

BOILER HEATING SURFACE	TUBES WITH ATTACHED DRUMS OR SHELLS FOR STORAGE OF WATER AND STEAM.
SUPERHEATED SURFACE	PROVIDES **MORE HEATING SURFACE THROUGH WHICH THE STEAM** MUST PASS AFTER LEAVING THE BOILER IF A FINAL SUPERHEATED STATE IS DESIRED.
ECONOMIZER	IS A **FEEDWATER PRE-HEATING DEVICE** WHICH UTILIZES STEAM MIXED WITH THE FEEDWATER.

• ENCLOSURE OR SETTING

WATER WALLS	WATER TUBES INSTALLED IN THE FURNACE TO PROTECT FURNACE AGAINST HIGH TEMPERATURE. SERVE AS EXTENSION OF HEAT TRANSFER AREA FOR FEED WATER.
FURNACE	ENCLOSES THE COMBUSTION EQUIPMENT TO UTILIZE EFFECTIVELY THE HEAT GENERATED.

• COMBUSTION EQUIPMENT

BURNER	USED IN **FIRE-TUBE BOILERS FOR FIRING LIQUID AND GASEOUS FUELS**
STOKER	USED IN **WATER-TUBE BOILERS FOR FIRING SOLID FUELS**

• AUXILIARIES AND ACCESSORIES

AIR PREHEATER	UTILIZING THE HEAT OF THE FLUE GASES TO **PRE-HEAT THE AIR NEEDED FOR COMBUSTION.**
FORCED-DRAFT FAN	**FORCES AIR INSIDE** TO SUPPORT FUEL COMBUSTION
INDUCED-DRAFT FAN	SITUATED AT THE BOTTOM OF THE CHIMNEY OR SMOKESTACK, **EXTRACTS FLUE GASES OUT.**
SOOT BLOWER	**REMOVES SOOT AROUND STEAM PIPES**, EMPLOYS THE USE OF EXTRACTED STEAM FROM THE MAIN STEAM LINE.
BLOWDOWN VALVE	IMPURITIES THAT SETTLE IN THE MUD DRUM ARE REMOVED; ALSO CALLED **BLOW-OFF VALVE.**
BREECHING	DUCT CONNECTING **BOILER TO CHIMNEY**
BAFFLES	**DIRECT THE FLOW OF THE HOT GASES** TO EFFECT EFFICIENT HEAT TRANSFER
FUSIBLE PLUG	A METAL PLUG WITH A DEFINITE MELTING POINT THROUGH WHICH **THE STEAM IS RELEASED IN CASE OF EXCESSIVE TEMPERATURE** WHICH IS **CAUSED BY LOW WATER LEVEL.**
SAFETY VALVE	SAFETY DEVICE **WHICH AUTOMATICALLY RELEASES THE STEAM IN CASE OF OVER-PRESSURE**

COMPUTATION

BOILER HEATING SURFACE

TOTAL AREA WHERE WATER AND GASES EXCHANGE HEAT

$$HS = \frac{1}{2}A_1 + A_2 + \frac{2}{3}A_3 - A_4$$

A_1 = AREA OF SHELL

$A_1 = \pi DL$

A_2 = INSIDE AREA OF ALL TUBES

$A_2 = n(\pi d_i L)$

A_3 = REAR HEAD AREA

$A_3 = \frac{\pi D^2}{4}$

A_4 = CROSS-SECTIONAL AREA OF TUBE SECTION

$A_4 = n\left(\frac{\pi d_o^2}{4}\right)$

D = DIAMETER OF SHELL

d_i = INSIDE Ø, d_o = OUTSIDE Ø, t = THICKNESS, L = LENGTH, n = NUMBER } TUBE

RATED BOILER HORSEPOWER

WATER-TUBE BOILER

$$\text{RATED Bo. Hp} = \frac{HS(\text{in m}^2)}{0.91}$$

FIRE-TUBE BOILER

$$\text{RATED Bo. Hp} = \frac{HS(\text{in m}^2)}{1.1}$$

DEVELOPED BOILER HORSEPOWER

$$\text{DEVELOPED Bo. HP} = \frac{m_s(h_s - h_f)}{35{,}322}$$

$1\ \text{Bo. HP} = 35322\ \frac{kJ}{hr} \rightarrow = 9.81\ kW$

PERCENT RATING

$$\%\,\text{RATING} = \frac{\text{DEVELOPED Bo. HP}}{\text{RATED Bo. HP}}$$

→ ACTUAL

→ IDEAL

ASME EVAPORATION UNITS

$$A.E.U. = m_s(h_s - h_f)$$

FACTOR OF EVAPORATION

$$FE = \frac{h_s - h_f}{2257}$$

EQUIVALENT EVAPORATION	$m_s \times FE$
ACTUAL SPECIFIC EVAPORATION (BOILER ECONOMY)	$\frac{m_s}{m_f}$
EQUIVALENT SPECIFIC EVAPORATION	$\frac{m_s}{m_f} \times FE$

EASY TO MEMORIZE!!

EVAP. = m_s

EVAP. + "SPECIFIC" → m_s/m_f

EVAP. + "EQUIVALENT" → $m_s \cdot FE$

BOILER EFFICIENCY OR OVERALL THERMAL EFFICIENCY

MEASURE OF ABILITY OF BOILER OR STEAM GENERATOR TO TRANSFER HEAT GIVEN BY FURNACE TO WATER AND STEAM

$$e_{bo} = \frac{m_s(h_s - h_f) + m_{rs}(h_{ro} - h_{ri}) + m_{bo}(h_{bo} - h_f)}{m_f Q_h}$$

IF NO REHEATER & BOILER BLOWDOWN $\rightarrow$ $e_{bo} = \frac{m_s(h_s - h_f)}{m_f Q_h}$

m_s = MASS OF STEAM
m_{rs} = MASS OF REHEATED STEAM
m_{bo} = MASS OF WATER BLOWDOWN
h_s = ENTHALPY OF STEAM
h_f = ENTHALPY OF FEEDWATER
h_{ro} = LEAVING } H OF REHEAT
h_{ri} = ENTERING }
h_{bo} = H OF SATURATED LIQUID @ BOILER PRESSURE

NET BOILER EFFICIENCY

$$e_{bo_{NET}} = \frac{m_s(h_s - h_f) - \text{POWER CONSUMED BY AUXILIARIES}}{m_f Q_h}$$

BOILER AND FURNACE EFFICIENCY

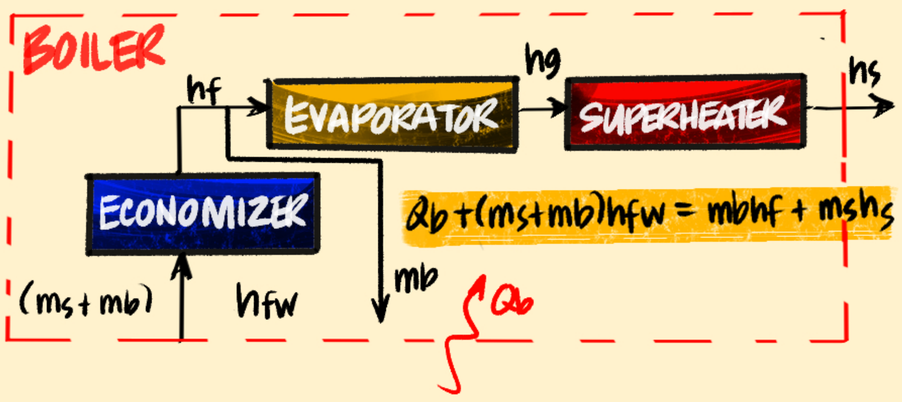
$$e_{bf} = \frac{m_s(h_s - h_f)}{m_f Q_h - m_{ash} Q_{ash}}$$

m_{ash} = AMOUNT OF ASH REFIRED
Q_{ash} = HHV OF ASH

GRATE EFFICIENCY

$$e_{GRATE} = \frac{1 - m_c Q_c}{Q_h}$$

m_c = AMOUNT OF CARBON IN REFUSE OR ASH



BOILER BLOWDOWN IS THE REMOVAL OF WATER FROM A BOILER. ITS PURPOSE IS TO CONTROL BOILER WATER PARAMETERS WITHIN PRESCRIBED LIMITS TO MINIMIZE SCALE, CORROSION, CARRYOVER, AND OTHER SPECIFIC PROBLEMS.

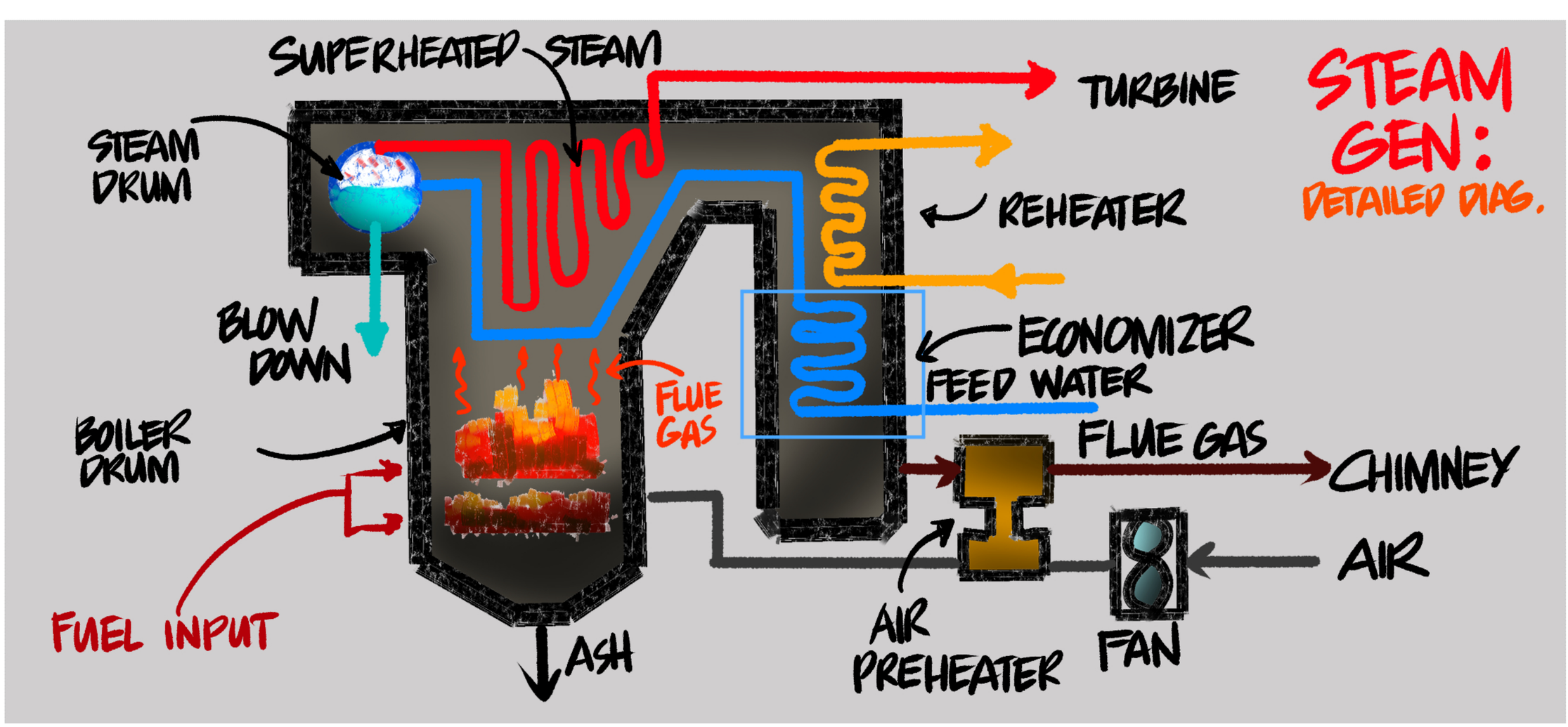
REQUIREMENTS AND SPECIFICATIONS

NO PART OF THE STEAM GEN. SHOULD BE CLOSER THAN **1 METER FROM** ANY WALL	
BOILER ROOMS SHOULD BE PROVIDED WITH **2 DOORS ON OPPOSITE ENDS**	
BRICKWORK SHOULD BE PROVIDED WITH SUFFICIENT EXPANSION JOINTS BOTH VERTICALLY AND HORIZONTALLY TO TAKE CARE OF EXPANSION AT OPERATING TEMPERATURE	
MAXIMUM ALLOWABLE WORKING PRESSURE	$P_{MAX} = \frac{TS_u \times t \times E}{R_i \times FS}$ TS = ULT. STRENGTH E = EFF. OF LONG. JOINT R_i = INSIDE RADIUS
FOR FUSION WELDING	90%
FACTOR OF SAFETY OF REINSTALLED OR SECOND-HAND BOILERS	6
AGE LIMIT OF HORIZONTAL BOILER OPERATING AT **0.345 MPA**	30 YEARS
DEAERATING HEATERS ARE NOT EMPLOYED, TEMP. OF FEED OF WATER	102°C
DEAERATING HEATERS ARE EMPLOYED, TEMP. OF FEED OF WATER	197°C
EACH BOILER SHOULD HAVE AT LEAST **3 OR MORE GAGE COCKS**, LOCATED ON THE SAME HORIZONTAL LINE AND **NOT LESS THAN 610 MM APART.**	

SUPERHEATER IS A HEAT EXCHANGER THAT IS USED TO INCREASE THE TOTAL ENERGY OF THE STEAM.

- A SUPERHEATER THAT IS EXPOSED DIRECTLY TO COMBUSTION HEAT IS CALLED **RADIANT SUPERHEATER.**
- A SUPERHEATER THAT IS EXPOSED TO STACK GASES IS CALLED **CONVECTION SUPERHEATER**

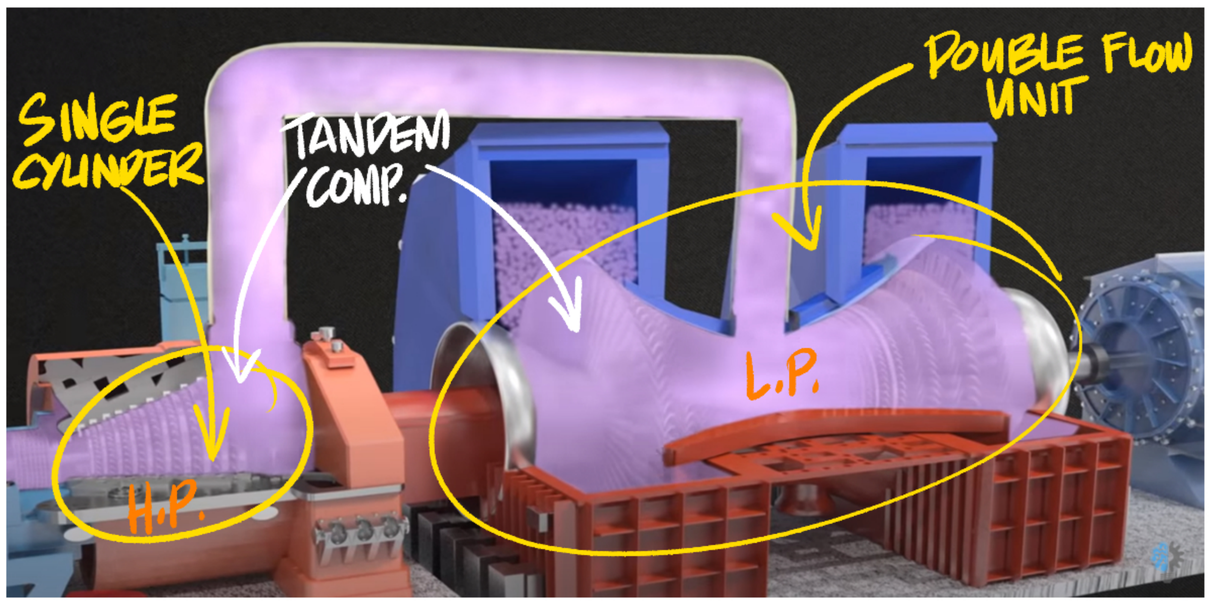
DESUPERHEATER (ATTEMPERATOR) USED TO DECREASE THE ENERGY OF THE STEAM AND IS DONE BY INJECTING WATER OR BY PASSING THE STEAM IN A CLOSED SYSTEM



STEAM TURBINE

EXPANSION OF STEAM THROUGH NUMEROUS STAGES IN THE TURBINE, CAUSES CONVERTS THE HEAT ENERGY OF THE STEAM INTO MECHANICAL WORK.

PRINCIPAL PARTS	
ROTOR	IS THE MAIN MOVING ELEMENT OF A TURBINE.
CASING (CYLINDER)	**PRINCIPAL STATIONARY ELEMENT**, IT SURROUNDS THE ROTOR AND HOLDS, INTERNALLY, ANY NOZZLES, BLADES, AND DIAPHRAGMS THAT **CONTROLS THE PATH AND PHYSICAL STATE** OF THE EXPANDING STEAM.
BEARINGS	TWO MAIN BEARINGS PLACED OUTBOARD OF THE SHAFT SEAL
SHAFT SEALS	PREVENTS **OUTFLOW AT THE HIGH-PRESSURE END** AND **AIR INFLOW AT THE VACUUM END.**
STEAM CONTROL	**REGULATE** THE FLOW OF STEAM TO PRODUCE **CONSTANT ROTATIVE SPEED** IN THE PRESENCE OF VARIABLE POWER DEMAND.
OIL SYSTEM	LUBRICATES THE BEARINGS.



CYLINDER ARRANGEMENT

A. SINGLE CYLINDER

- WITH ALL ROTATING BLADES ATTACHED TO ONE SHAFT AND THE STEAM FLOW ALL IN ONE DIRECTION.

B. DOUBLE FLOW UNITS

- SINGLE CYLINDER UNITS WITH STEAM ENTERING IN THE CENTER AND FLOWING IN TWO EQUAL QUANTITIES, BUT IN OPPOSITE DIRECTIONS ALONG THE SHAFT.

C. TANDEM-COMPOUND UNITS

- SINGLE FLOW HIGH PRESSURE TURBINE CONNECTED TO A DOUBLE FLOW LOW PRESSURE TURBINE

D. CROSS-COMPOUND UNITS

- DIFFER FROM TANDEM-COMPOUND UNITS ONLY IN THAT THE HIGH- AND LOW-PRESSURE ENDS ARE NOT ON THE SAME SHAFT.

E. STEEPLE- OR VERTICAL-COMPOUND UNITS

CLASSIFICATION

ACCORDING TO BLADE TYPE

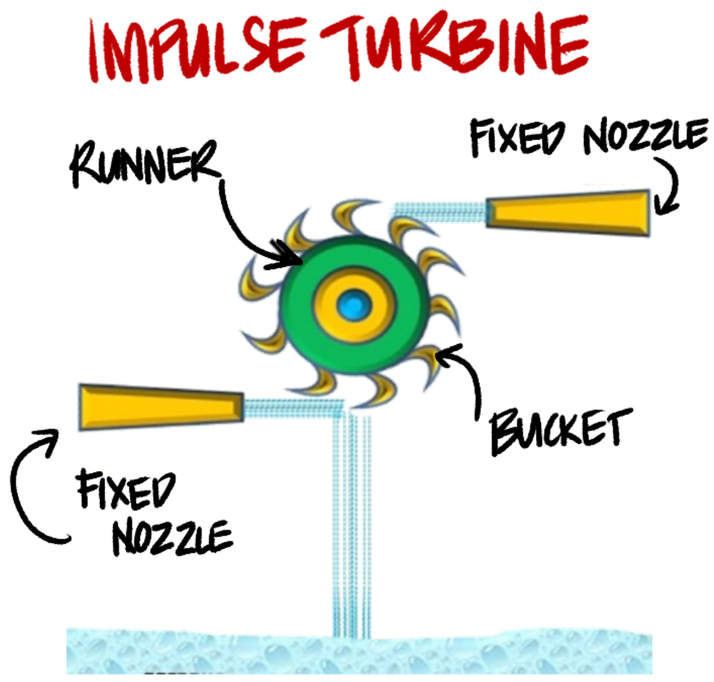
- **IMPULSE STAGES**

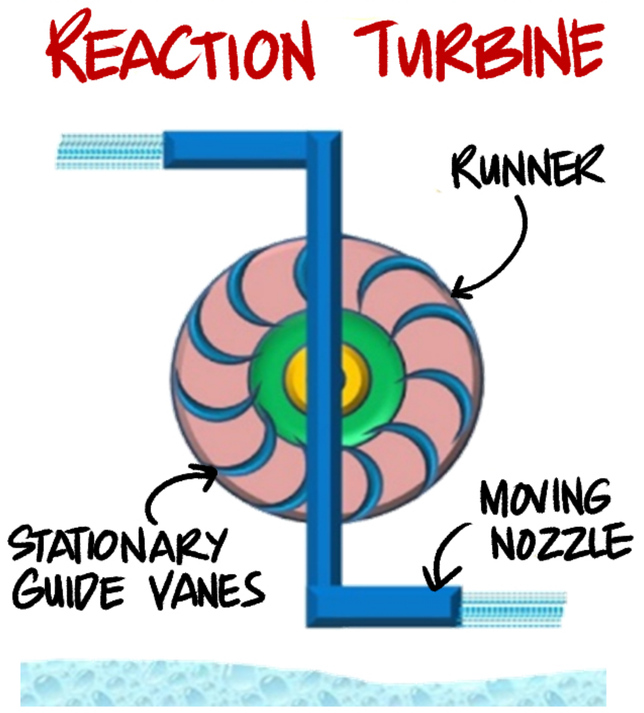
- CONSISTS OF A STATIONARY NOZZLE WITH ROTATING BUCKETS OR BLADES.
- THE STEAM EXPANDS IN THE NOZZLE

VELOCITY COMPOUND STAGE (CURTIS STAGE)	INVOLVES A **STATIONARY NOZZLE FOLLOWED BY SEVERAL ROTATING AND STATIONARY BUCKETS.** THE NOZZLE HAS **A LARGE PRESSURE DROP** WITH A RESULTING INCREASE IN VELOCITY.
PRESSURE COMPOUND STAGES (RATEAU STAGE)	INVOLVE **SEVERAL SETS OF NOZZLES WITH SMALL PRESSURE DROPS** THROUGH EACH SET OF NOZZLES AND COMPLETE VELOCITY DISSIPATION IN EACH ROW OF ROTATING BUCKETS.

- **REACTION STAGES**

- ARE COMPOSED OF ONE STATIONARY ROW OF BLADES AND ONE ROTATING ROW OF BLADES WITH A PRESSURE DROP OCCURRING IN EACH STATIONARY AND ROTATING ROW.
- THE STEAM EXPANDS IN THE BLADING

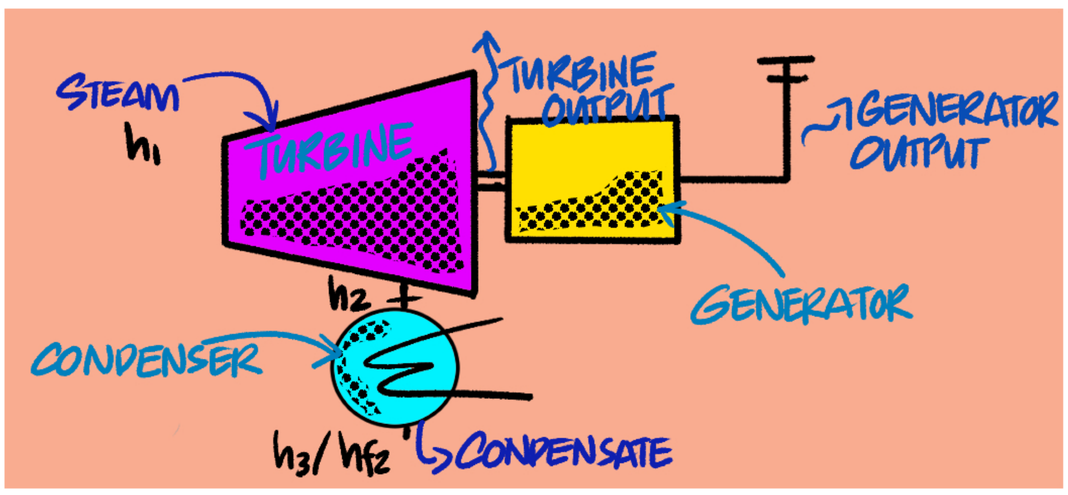




POWER RATING

- **INTERNAL POWER**
  - IS THE PRODUCT OF TORQUE AND ROTOR SPEED
- **NOMINAL RATING**
  - IS A DECLARED POWER CAPACITY EXPECTED TO BE THE MAXIMUM LOAD
- **CAPABILITY**
  - IS THE MANUFACTURER'S GUARANTEED MAXIMUM CONTINUOUS OUTPUT FOR A CLEAN TURBINE, OPERATING UNDER SPECIFIC THROTTLE AND EXHAUST CONDITIONS, WITH FULL EXTRACTION AT ANY OPENINGS
- **OVERLOAD CAPACITY**
  - IS THE DIFFERENCE BETWEEN CAPABILITY AND RATING

COMPUTATION



IDEAL AND ACTUAL TURBINE WORK

$$W_T = m_s(h_1 - h_2) \quad | \quad W_T' = m_s(h_1 - h_{2a}) \quad W_T' = W_T \eta_{st}$$

η_{st} → STAGE EFFICIENCY

TURBINE POWER OUTPUT

$$\text{TURBINE POW. OUT} = m_s(h_1 - h_2) \times \eta_T \quad | \quad \eta_T = \eta_{st} \times \eta_m$$

η_m → MECH. EFF.

GENERATOR EFFICIENCY

$$\eta_e = \frac{\text{GENERATOR OUTPUT}}{\text{TURBINE OUTPUT}} \quad | \quad \text{GENERATOR OUTPUT} = m_s(h_1 - h_2) \times \eta_T \times \eta_e$$

$m_s(h_1 - h_2) \times \eta_T$ → TURBINE OUTPUT

THERMAL EFFICIENCIES

☐ BRAKE THERMAL EFFICIENCY

$$e_{tb} = \frac{\text{TURBINE OUTPUT}}{m_s(h_1 - h_{f2})}$$

☐ COMBINED OR OVERALL THERMAL EFFICIENCY

$$e_{tc} = \frac{\text{GENERATOR OUTPUT}}{m_s(h_1 - h_{f2})}$$

☐ IDEAL RANKINE THERMAL EFFICIENCY

$$e_{tr} = \frac{h_1 - h_2}{h_1 - h_{f2}}$$

ENGINE EFFICIENCIES OF TURBINE

☐ BRAKE ENGINE EFFICIENCY

$$e_b = \frac{\text{BRAKE POWER}}{m_s(h_1 - h_2)}$$

☐ COMBINED/OVERALL ENGINE EFFICIENCY

$$e_c = \frac{\text{GENERATOR OUTPUT}}{m_s(h_1 - h_2)}$$

ADDITIONAL INFORMATION

STAGE EFFICIENCY

↳ MEASURES THE IRREVERSIBLE ENTROPY – INCREASING ACTION

$$\eta_{st} = 0.94(BE) - (2\% - 5\%\ \text{ROTATION \& LEAKAGE ALLOW})$$

BE → BLADE EFFICIENCY

0.94 → NOZZLE EFF.

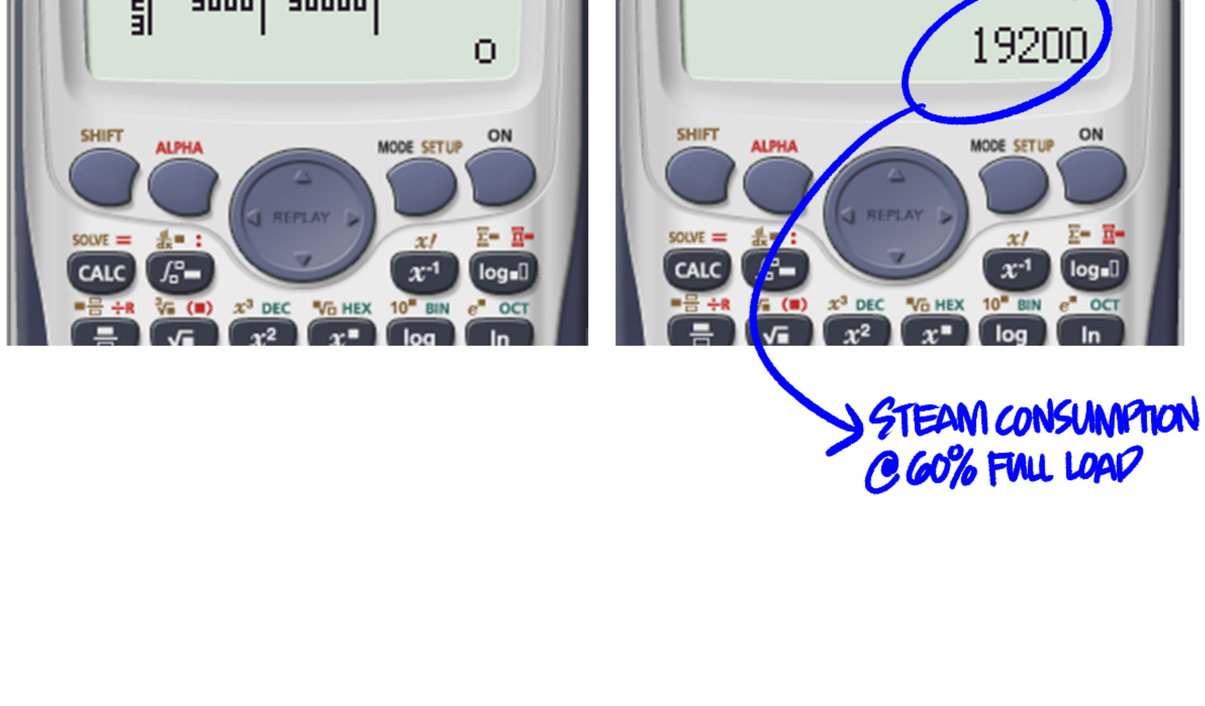
☐ IF WITH MOISTURE EFFECT

$$\eta_{st_M} = \eta_{st} - \text{MOISTURE EFFECT}$$

$$ME = (1 - x) + \frac{\Delta hi}{3490} \quad | \quad (1-x) \rightarrow \text{INITIAL MOIS. CONT.}; \ \Delta hi \rightarrow \text{kJ/kg; HEAT RELEASE}$$

WILLIAN'S LINE

IS A STRAIGHT LINE WHICH SHOWS THE RELATION BETWEEN THE STEAM CONSUMPTION AND THE LOAD OF STEAM TURBINE GENERATOR UNIT



STEAM ENGINE

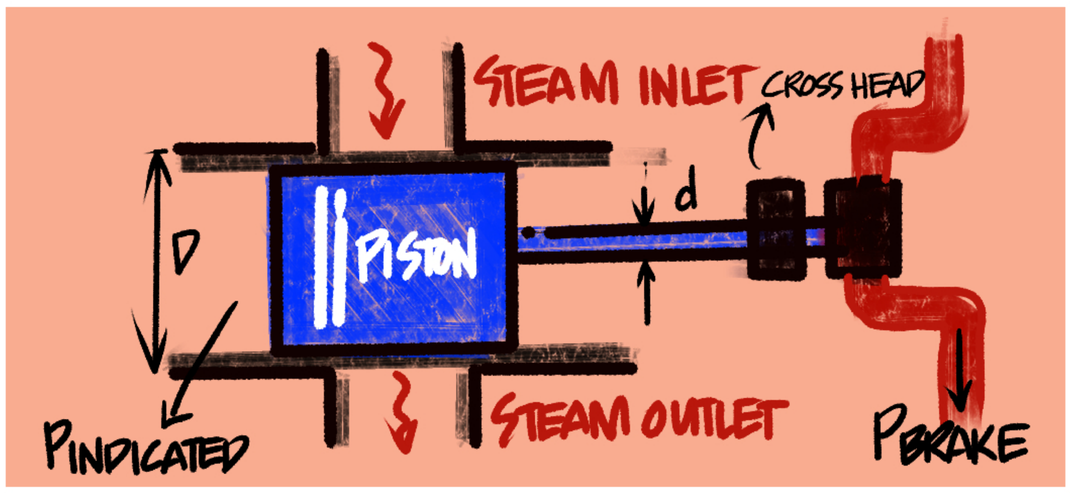
CONVERTS THE HEAT ENERGY OF THE STEAM INTO WORK IN THE FORM OF A **POSITIVE DISPLACEMENT, PISTON CYLINDER MECHANISM**

SINGLE ACTING ENGINE	WORK IS DONE ON **ONLY ONE** SIDE OF THE PISTON HAVING ONLY **ONE WORKING STROKE TO A REVOLUTION**
DOUBLE ACTING ENGINE	WORK IS DONE ON **BOTH** SIDES OF THE PISTON, HAVING **TWO WORKING STROKES TO A REVOLUTION**

IMPORTANT DEFINITION

ENGINE INDICATOR	TRACES THE ACTUAL P-V DIAGRAM
PLANIMETER	MEASURES THE AREA OF THE P-V DIAGRAM
DYNAMOMETER	MEASURES THE TORQUE
TACHOMETER	MEASURES THE SPEED OF THE ENGINE

COMPUTATION



VOLUME DISPLACEMENT

☐ PISTON ROD NEGLECTED

DOUBLE ACT. 1 REV = 2 STROKES

$$V_D = 2\left[\left(\frac{\pi}{4}\right)D^2LN\right]$$

☐ PISTON ROD CONSIDERED

$$V_D = \frac{\pi}{4}D^2LN + \frac{\pi}{4}(D^2 - d^2)LN$$

INDICATED POWER

$$P_i = P_{iMEP}(V_D)$$

BRAKE POWER

$$P_b = P_{bMEP}(V_D) = 2\pi TN$$

FRICTION POWER

$$\text{FRICTION POWER} = P_{IND.} - P_{BRAKE}$$

MECHANICAL EFFICIENCY

$$e_m = \frac{\text{BRAKE POWER}}{\text{INDICATED POWER}}$$

THERMAL EFFICIENCY

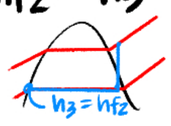
☐ INDICATED THERMAL EFFICIENCY

$$e_{ti} = P_{IND}/h_1 - h_{f2}$$

☐ BRAKE THERMAL EFFICIENCY

$$e_{tb} = P_{BRAKE}/h_1 - h_{f2}$$

NOTE: $h_{f2} = h_3$



☐ IDEAL RANKINE THERMAL EFFICIENCY

$$e_{tR} = (h_1 - h_2)/h_1 - h_{f2}$$

ENGINE EFFICIENCY

☐ INDICATED ENGINE EFFICIENCY

$$e_{ti} = P_{IND}/h_1 - h_2$$

☐ BRAKE ENGINE EFFICIENCY

$$e_{tb} = P_{BRAKE}/h_1 - h_2$$

ADDITIONAL INFORMATION

MEAN EFFECTIVE PRESSURE

☐ EXPANSION RATIO

$$r = \frac{\text{STROKE VOLUME}}{\text{CUT-OFF}}$$

IF WITH CLEARANCE VOLUME

$$r = \frac{\text{STROKE VOL.} + \text{CLEARANCE VOL.}}{\text{CUTOFF} + \text{CLEARANCE VOL.}}$$

if $SV = 1 \rightarrow ER = \frac{1+c}{\text{CUTOFF} + c}$

☑ ADMISSION AREA

$$A_A = P(\text{CUT-OFF})$$

☑ EXPANSION AREA

$$E_A = P_1V_1\ln(r)$$

☑ GROSS AREA

$$G_A = E_A + A_A$$

☑ MEAN GROSS PRESSURE

$$P_{MEAN\ GROSS} = \frac{G_A}{\text{LENGTH}}$$

☑ MEAN EFFECTIVE PRESS.

$$P_{MEP} = P_{MGP} - P_{BACK}$$

◎ ACTUAL P_{MEP}

$$P_{MEP_{ACT.}} = P_{MEP}(DF)$$

DIAGRAM FACTOR

OTHER ELEMENTS OF PLANT DESIGN

CONDENSER

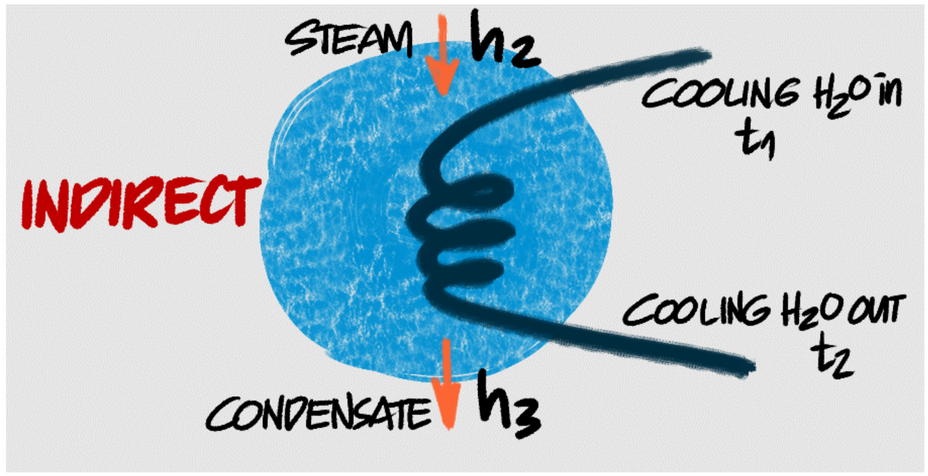
A HEAT EXCHANGER WHERE STEAM ENTERS AT THE TOP AND THE CONDENSATE IS COLLECTED IN THE HOT WELL AT THE BOTTOM WHILE COOLING WATER FLOWS THROUGH THE TUBES.

FUNCTIONS OF STEAM CONDENSER

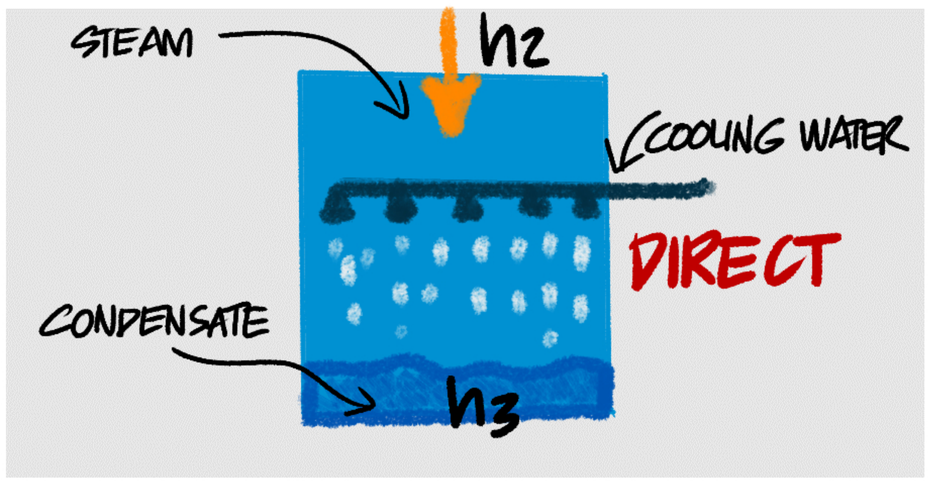
A. **CONVERT STEAM TO LIQUID** BEFORE ENTERING THE STEAM-GENERATING UNIT.
B. **CREATE A VACUUM AT TURBINE EXHAUST** THEREBY INCREASING TURBINE POWER.

CLASSIFICATION OF CONDENSERS:

- **SURFACE CONDENSERS**
  - WHERE STEAM AND COOLING WATER ARE **NOT ALLOWED TO MIX**; COMMONLY **SHELL AND TUBE DESIGN**



- **DIRECT-CONTACT CONDENSER (MIXING)**
  - ALSO CALLED **JET CONDENSERS** , WHERE STEAM AND COOLING WATER ARE **ALLOWED TO MIX.**



HEAT BALANCE

$$m_w c_{pw}(t_2 - t_1) = m_s(h_s - h_f) \times E_h$$

E_h = HEAT EXTRACTION FACTOR

VACUUM EFFICIENCY

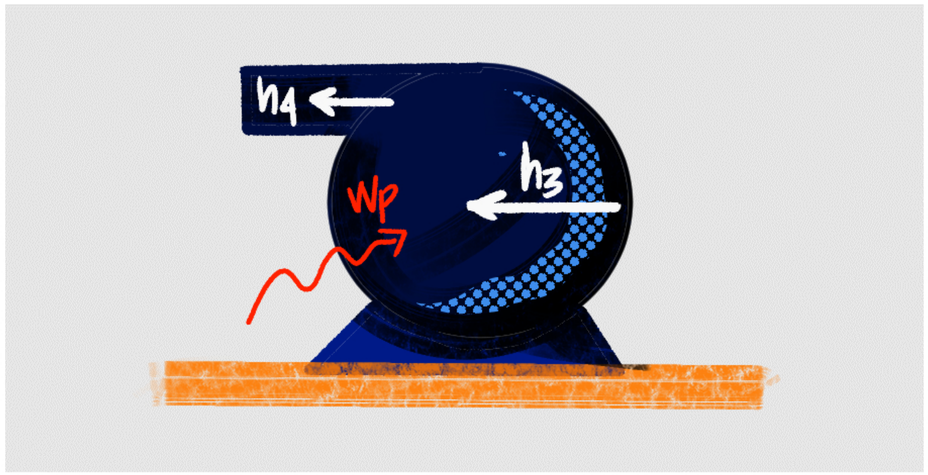
$$e_v = \frac{P_{VACUUM}}{P_{ATM} - P_{COND}} = \frac{P_{ATM} - P_{SAT}}{P_{ATM} - P_{TOTAL}}$$

P_{SAT} @ T_{COND}

P_{TOTAL} → TOTAL CONDENSER PRESSURE

FEEDWATER PUMP

WHOSE FUNCTION IS TO **INCREASE THE PRESSURE EXISTING ON A LIQUID** AN INCREMENT SUFFICIENT TO THE REQUIRED SERVICE. THIS PUMPS BOILER FEEDWATER



PUMP WORK

$$W_p = m(h_4 - h_3)$$
$$W_p = m v_3 (P_4 - P_3)$$

POWER INPUT OF THE PUMP

$$W_{p(IN)} = \frac{m_s(h_4 - h_3)}{e_p}$$

GAS LOOP

THE GAS PASSAGES, CHIMNEY, THE FUEL AND AIR SUPPLY ARRANGEMENT, ASH REMOVAL, CONTROL AND REGULATORY APPARATUS ARE WHAT CONSTITUTES THE GAS LOOP.

FUNCTIONS OF GAS LOOP

- TO CREATE PROPER CONDITIONS FOR COMBUSTION
- TO SUPPLY INGREDIENTS FOR COMBUSTION IN PROPER PROPORTIONS
- TO MOVE PRODUCTS OF COMBUSTION TO THE ATMOSPHERE

TYPES OF FLUE GAS CLEANING EQUIPMENTS

1. **GRAVITATIONAL SEPARATORS**
2. **INERTIAL SEPARATORS**
   - BAFFLE
   - LOUVRE
   - CYCLONE
3. **ELECTRICAL PRECIPITATOR**

DRAFT NOMENCLATURE OF GAS LOOP:

NATURAL DRAFT	PRESSURE DIFFERENCE CREATED BY CONFINING A COLUMN OF HEAT GAS (CHIMNEY)
FORCED DRAFT	DRAFT CREATED BY FANS
INDUCED DRAFT	COMBINATION OF FORCED AND INDUCED, OR FORCED AND NATURAL DRAFT CHOSEN THAT THE GAS LOOP PRESSURE IS NEARLY ATMOSPHERIC AT FURNACE
REQUIRED DRAFT	PRESSURE REQUIRED TO OVERCOME THE SUM OF THE DRAFT LOSSES AT ANY FLOW RATE.
AVAILABLE DRAFT	THE DRAFT THAT THE FANS AND/OR CHIMNEY CAN PRODUCE AT ANY FLOW RATE

DRAFT LOSS DUE TO FRICTION IN AIR DUCTS, GAS BREECHINGS, AND CHIMNEY

$$D = f\left(\frac{H}{R}\right)\left(\frac{V^2}{2g}\right)\times\rho\times\frac{1\ cmH_2O}{10\ \frac{kg}{m^2}}$$

$$1\ cmH_2O = 10\ \frac{kg}{m^2}$$

D = DRAFT LOSS; cmH_2O
ρ = GAS DENSITY, $\frac{kg}{m^3}$
V = VELOCITY $\frac{m}{s}$
H = LENGTH OF CONDUIT, m
R = HYDRAULIC RADIUS, m
f = FRICTION FACTOR

AIR AGAINST STEEL	0.005	FLUE GAS AGAINST STEEL	0.014
AIR AGAINST MASONRY AND CONCRETR	0.007	FLUE GAS AGAINST MASONRY AND CONCRETE	0.014

FAN WORK

$$W = v\Delta P + \left[\frac{V_2^2 - V_1^2}{2g}\right]$$

v = SPECIFIC VOLUME; m^3/kg
ΔP = STATIC PRESSURE; kg/m^2
V = VELOCITY; m/s
W = WORK ADDED TO AIR; $\frac{kg\text{-}m}{kg\ AIR}$

TOTAL AIR HORSEPOWER

$$HP_t = \frac{Q\Delta P_t}{450}\ ;\ hp\ of\ AIR$$

Q = FLOW; CFM
ΔP_t = TOTAL DRAFT IN cmH_2O

STATIC AIR HORSEPOWER

$$HP_s = \frac{Q\Delta P_s}{450}\ ;\ hp\ of\ AIR$$

ΔP_s = STATIC DRAFT cmH_2O

FAN EFFICIENCIES

- TOTAL FAN MECHANICAL EFFICIENCY

$$e_{ft} = \frac{\text{TOTAL AIR HP}}{\text{STATIC HP}}$$

- STATIC FAN EFFICIENCY

$$e_{fs} = \frac{\text{STATIC AIR HP}}{\text{STATIC HP}}$$

- MANOMETRIC EFFICIENCY

$$e_{mn} = \frac{\text{ACTUAL DRAFT}}{\text{THEORETICAL DRAFT}}$$

AVAILABLE DRAFT PER 30-M CHIMNEY HEIGHT

$$D_{30} = K(P_a - P_g) - 0.007578\sqrt{\frac{V^5}{Q}}\ ;cmH_2O$$

P_a = DENSITY OF AIR } $\frac{kg}{m^3}$
P_g = DENSITY OF GAS }
Q = FLOW; m^3/s
V = VELOCITY; m/s

K = 2.7 BRICK CHIMNEY
= 2.4 STEEL STACKS

PRESSURE INCREMENT TO GAS VELOCITY

$$V_2^2 - V_1^2 = C^2 \times 2gH$$

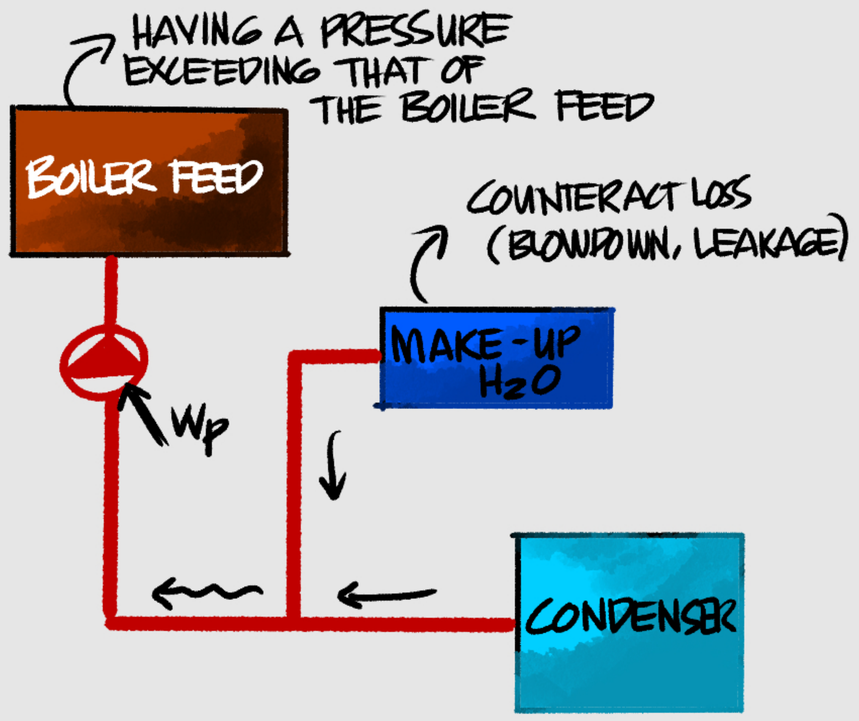
→ BERNOULLI'S PRINCIPLE (ASSUMING INCOMPRESSIBLE FLUID)

C = VELOCITY COEFFICIENT (GENERALLY USUALLY UNITY)

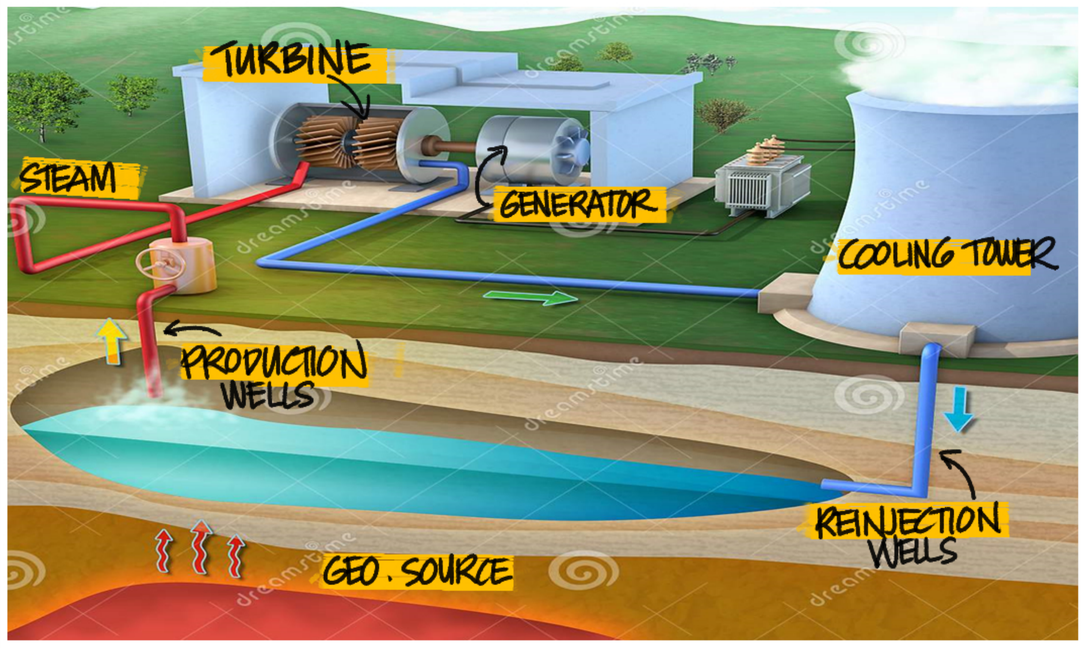
FEEDWATER LOOP

FUNCTIONS OF FEEDWATER LOOP:

- CONVERT CONDENSATE INTO HOT BOILER FEED WATER AT A PRESSURE SUFFICIENTLY ABOVE THE BOILER PRESSURE.
- MAKE-UP WATER IS ADDED TO COUNTERACT LOSS OF WORKING MEDIUM THROUGHOUT THE CYCLE (BLOWDOWN, LEAKS, ETC..)



GEOTHERMAL POWER PLANT



- **HEAT FROM THE EARTH**
- HEAT IS EXTRACTED BY DRILLING STEAM WELLS. THIS PLANT USE THE SAME STANDARD COMPONENTS OF A STEAM POWER PLANT.

GEOTHERMAL PLANTS IN THE PHILIPPINES		
TIWI GEOTHERMAL	330 MW	ALBAY
MAKILING-BANAHAW (MAK-BAN)	330 MW	LOS BANOS, LAGUNA
TONGONAN	112.5 MW	LEYTE
PALIMPINON-DAUIN	112.5 MW	NEGROS ORIENTAL

MAGMA	MOLTEN METAL WITHIN THE EARTH. BASICALLY NICKEL-IRON IN COMPOSITION.
FUMAROLE	A CRACK IN THE EARTH THROUGH WHICH THE GEOTHERMAL SUBSTANCES PASSES.
GEYSER	A VENT, EJECTS A COLUMN OF HOT WATER AND STEAM.
WELL-BORE PRODUCT	THE EFFLUENT (DISCHARGE) COMING OUT FROM THE GEOTHERMAL WELL AS PRODUCED AFTER DRILLING. (STEAM, HOT WATER, OR BOTH)
STEAM-DOMINATED GEOTHERMAL FIELD (VAPOR DOMINATED)	REFERS TO A GEOTHERMAL PLANT WITH ITS WELL **PRODUCING ALL STEAM** AS THE WELL-BORE PRODUCT.
LIQUID-DOMINATED GEOTHERMAL FIELD (HOT WATER DOMINATED)	THE WELL-BORE PRODUCT FOR THIS TYPE OF FIELD IS PRACTICALLY **ALL HOT WATER, PRESSURIZED.**

SOURCES OF GEOTHERMAL ENERGY

- **HYDROTHERMAL FLUIDS**
  - MADE UP OF **HOT WATER, STEAM AND MINERALS.** THE ONLY FORM OF ENERGY CURRENTLY BEING TAPPED FOR COMMERCIAL HEAT AND ELECTRIC ENERGY SUPPLY.
- **GEOPRESSURIZED BRINES**
  - HOT WATER EXISTING AT PRESSURES ABOVE THE NORMAL HYDROSTATIC GRADIENT AND **CONTAINING DISSOLVED METHANE.**
  - – FOUND IN DEPTHS **EXCEEDING 3 KM**
- **HOT DRY ROCK**
  - A WATER-FREE, IMPERMEABLE ROCK AT HIGH TEMPERATURE
  - HIGH-PRESSURE WATER INJECTED THROUGH ONE OR MORE WELLS TO CREATE OR ENHANCE EXISTING NATURAL FRACTURE SYSTEM WITH LIMITED ACCESS TO GROUND WATER FLOW.
- **MAGMA**
  - IS CHARACTERIZED BY **MOTION OR PARTIALLY MOLTEN ROCK** WITH TEMPERATURE REACHING AS HIGH **1200 C.**

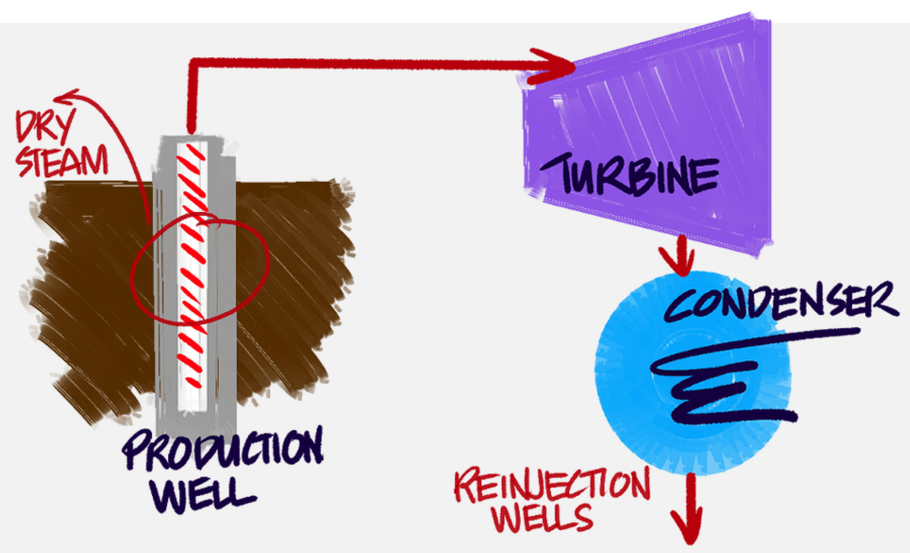
FLASHING

DROPPING THE PRESSURE OF THE WATER DOMINATED MIXTURE IN ORDER FOR IT TO TURN TO STEAM.

TYPES OF GEOTHERMAL PLANTS

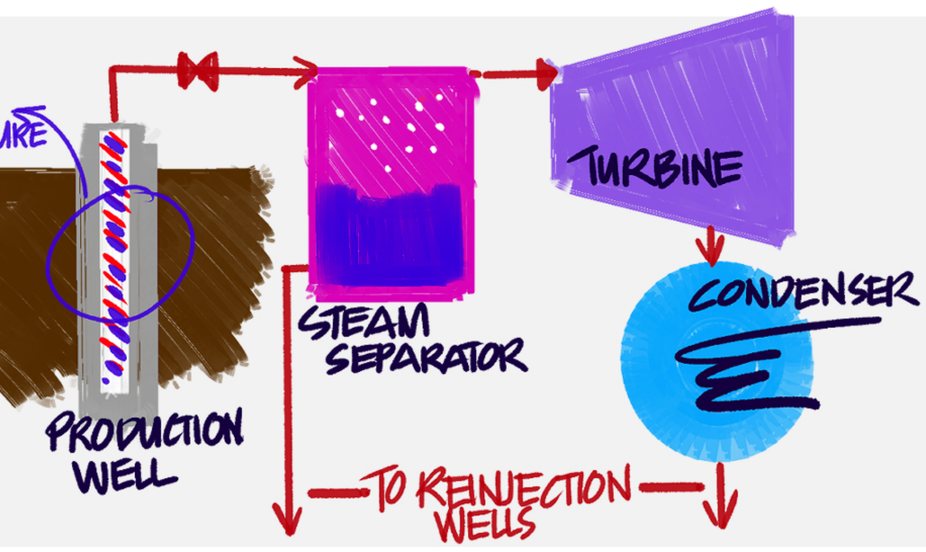
DRY OR SUPERHEATED STEAM

- **VAPOR-DOMINATED (DRY OR SUPERHEATED STEAM);** STEAM DIRECTLY RUNS THE TURBINE.



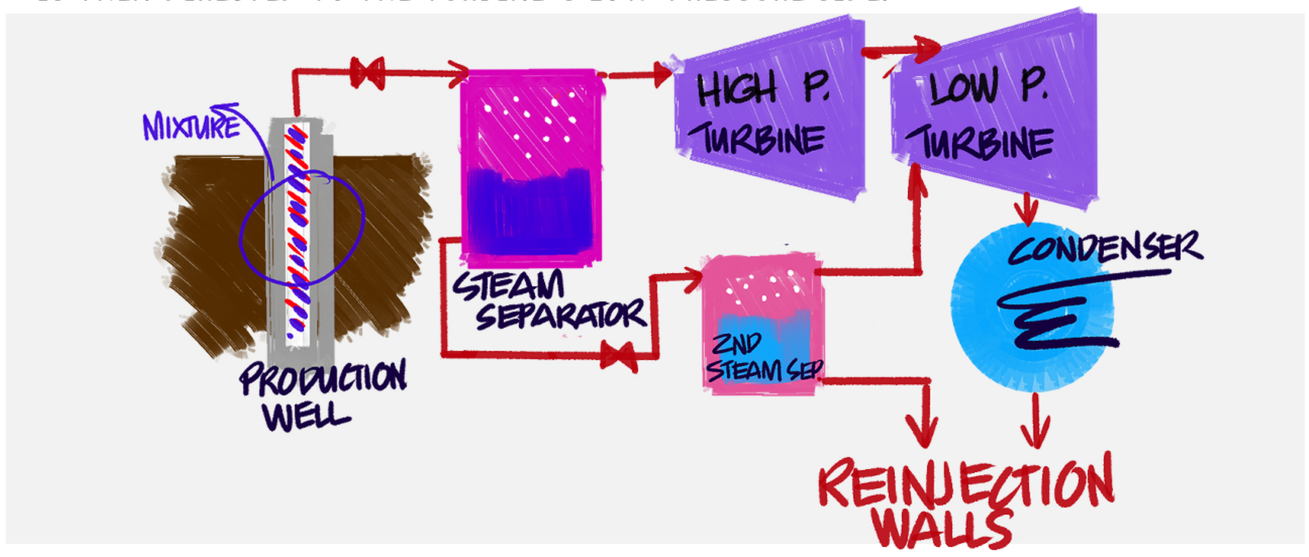
SINGLE-FLASHED OR SEPARATED STEAM

- HOT WATER-DOMINATED (MIXTURE OF STEAM AND HOTWATER); **EMPLOYS THE USE OF STEAM SEPARATOR;** RE-INJECTS HOT WATER, STEAM GOES TO TURBINE.

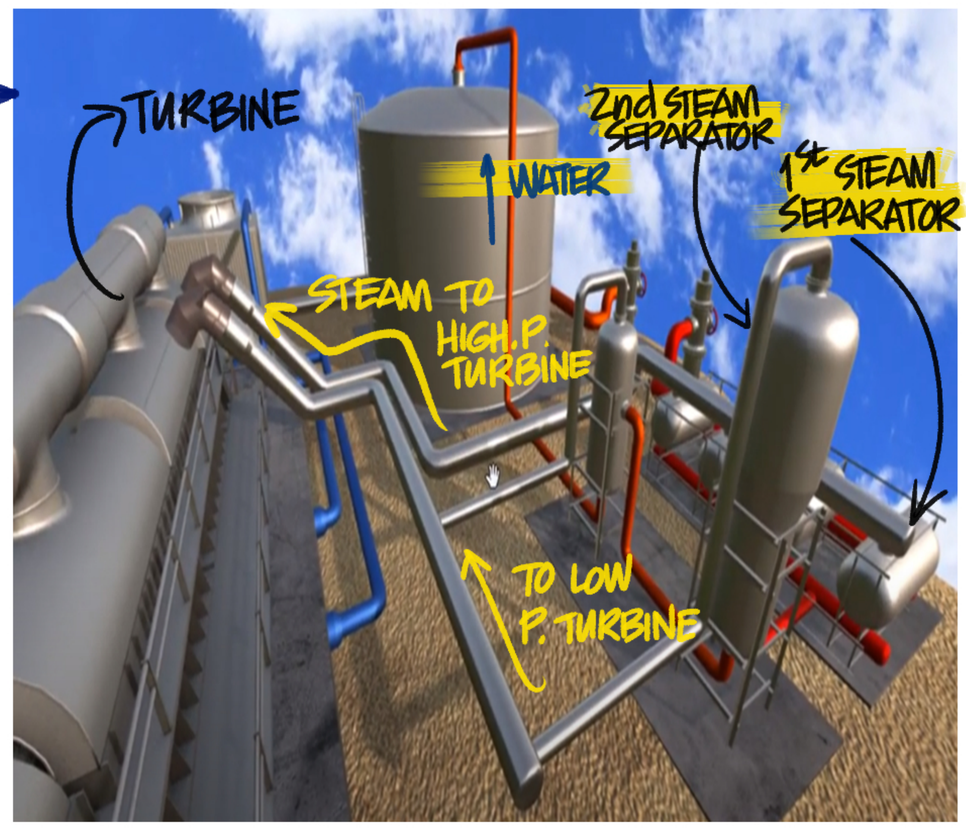


SEPARATED STEAM/HOT WATER-FLASHED OR DOUBLE FLASHED

FLASHER IS ADDED AT THE HOT WATER-END OF THE STEAM SEPARATOR; IT FURTHER EXTRACTS THE STEAM WHICH WERE NOT EXTRACTED IN THE SEPARATOR; SUCH STEAM IS THEN DIRECTED TO THE TURBINE'S LOW-PRESSURE SIDE.

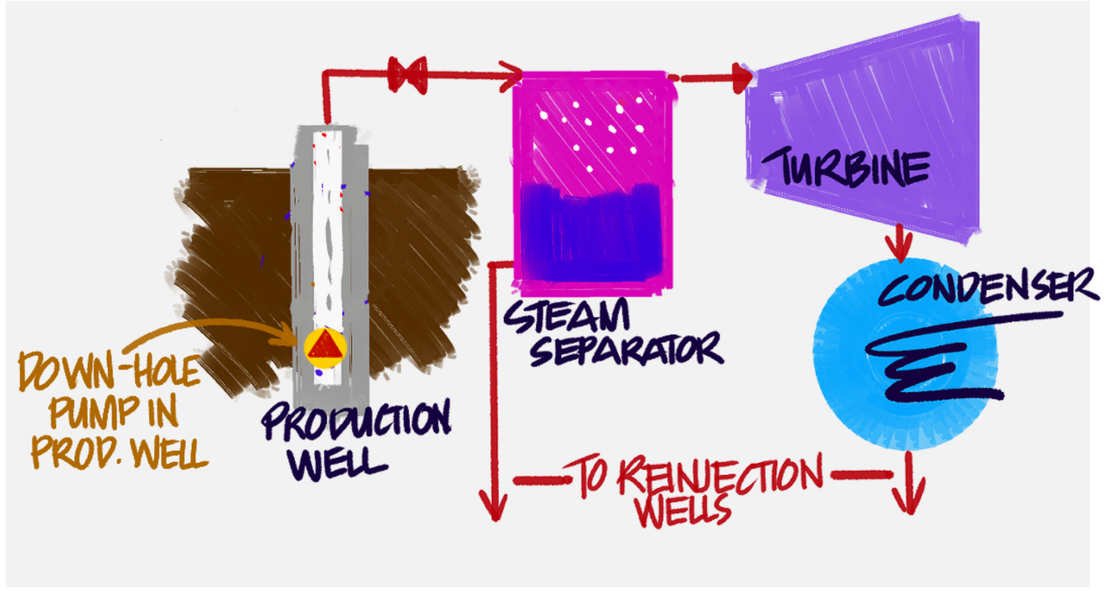


3D MODEL



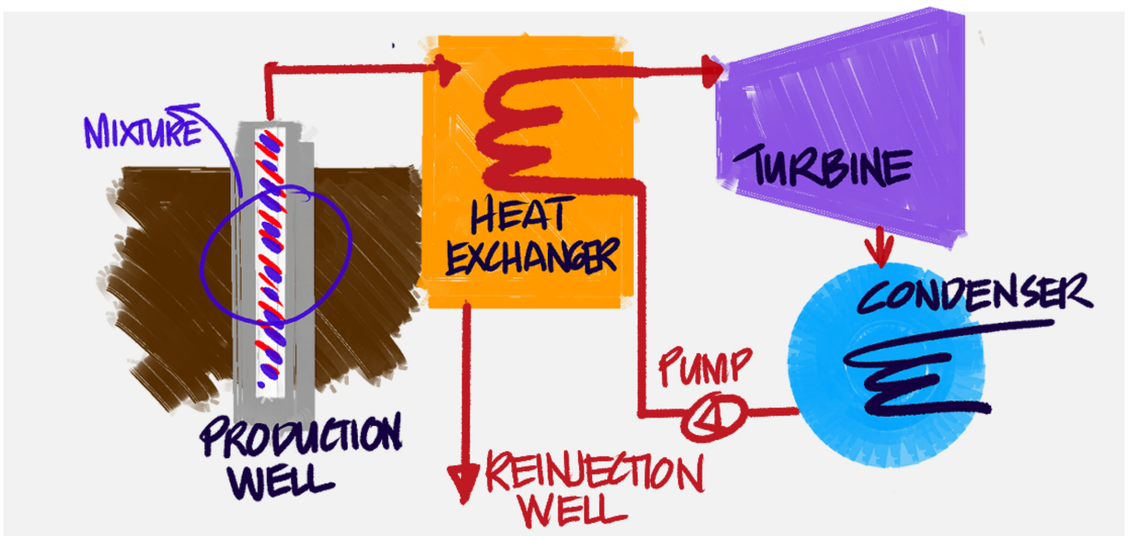
SINGLE-FLASHED WITH PUMPED WELL

EMPLOYS DOWN-HOLE PUMP IN PRODUCTION WELLS FOR BETTER STEAM RECOVERY.

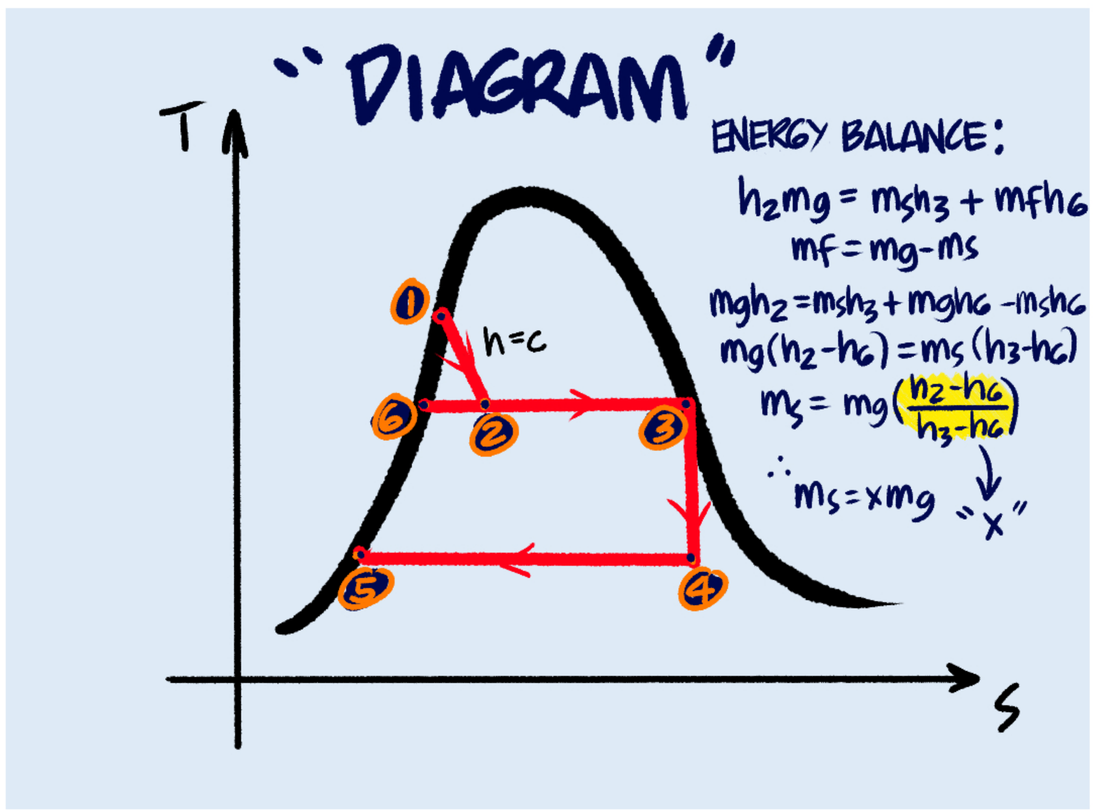


BINARY GEOTHERMAL PLANT

LIKE THE BINARY MERCURY-STEAM CYCLE, IT USES TWO WORKING FLUIDS, ONE IS THE STEAM FROM THE PRODUCTION WELL, THE OTHER IS FEEDWATER; THE HEAT EXCHANGER SERVES THE FUNCTION OF THE BOILER.



PERFORMANCE OF FLASHED – STEAM GEO PLANT



MASS FLOW RATE OF STEAM

$$m_s = x m_g \qquad h_1 = h_2 = h_{f2} + x h_{fg2}$$

MASS OF STEAM ← $m_s = x m_g$ → MASS OF GROUND WATER

QUALITY AFTER THROTTLING

TURBINE OUTPUT

$$W_T = m_s(h_3 - h_4) \times e_t$$

e_t = TURBINE EFFICIENCY

GENERATOR OUTPUT

$$W_e = W_t \times e_{gen}$$
$$W_e = [m_s(h_3 - h_4)]\, e_t \times e_{gen}$$

e_{gen} = GENERATOR EFFICIENCY

HEAT REJECTED IN CONDENSER

$$Q_R = m_s(h_4 - h_5)$$

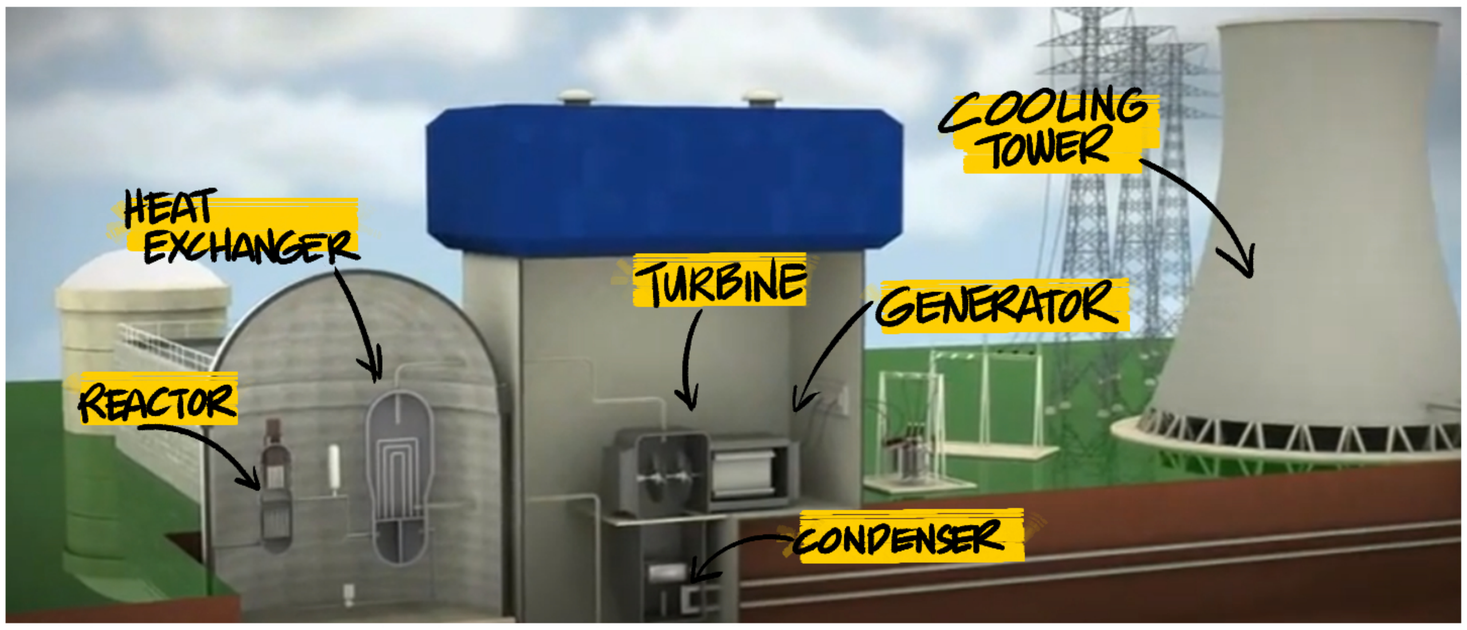
OVERALL PLANT EFFICIENCY

$$e_c = \frac{W_t}{m g h_1} = \frac{m_s(h_3 - h_4) e_t}{m g h_1}$$

NUMBER OF WELLS

$$\text{NO. OF WELLS} = \frac{\text{MASS OF GROUND WATER}}{\text{CAPACITY OF EACH WELL}}$$

NUCLEAR POWER PLANT

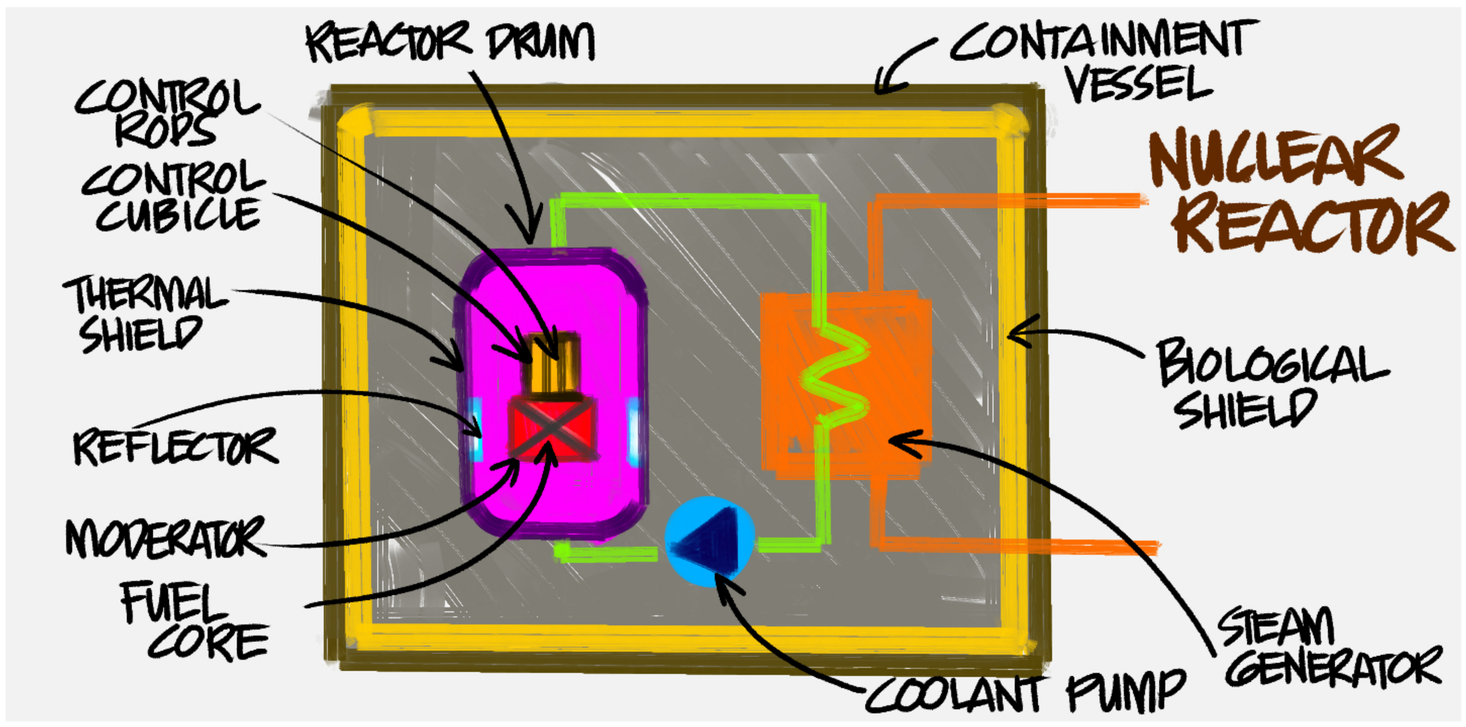


- NUCLEAR ENERGY IS CONVERTED INTO HEAT TO BE USED IN PRODUCING STEAM FOR TURBINES

FISSION VS. FUSION???

- **FISSION**
  - RELEASE OF ENERGY BY **SPLITTING** HEAVY NUCLEI SUCH **AS URANIUM-235** AND **PLUTONIUM-239**
- **FUSION**
  - RELEASE OF ENERGY BY **COMBINING** TWO LIGHT NUCLEI SUCH AS **DEUTERIUM** AND **TRITIUM**

ISOTOPES	THE SAME CHEMICAL PROPERTIES BUT DIFFERENT ATOMIC WEIGHTS BECAUSE OF DIFFERENT NUMBERS OF NEUTRONS.
ALPHA PARTICLES	HAS A POSITIVE CHARGE AND A **MASS OF 4**. COMPOSED OF TWO PROTONS AND TWO NEUTRONS; THEY ARE THE NUCLEUS OF THE **HELIUM** ATOM.
BETA PARTICLES	ELECTRONS EMITTED FROM THE NUCLEUS OF AN ATOM
GAMMA RAYS	SIMILAR TO X-RAYS IN THAT THEY ARE ELECTROMAGNETIC
FUEL CORE	RADIOACTIVE MATERIALS (**U235** WITH **U238**). SOURCE OF ENERGY
MODERATOR	SLOWS DOWN THE NEUTRONS TO THERMAL ENERGY, MADE OF **CARBON AND BERYLLIUM**
CONTROL RODS (NEUTRON-ABSORBERS)	STEEL RODS (**BORON COATED**) THAT CONTROL THE REACTOR.
REFLECTOR	MADE OF **LEAD/CARBON.** SURROUNDS THE CORE TO BOUNCE BACK ANY LEAKAGE OF NEUTRONS
THERMAL SHIELD	PREVENTS ESCAPE OF RADIATION FROM REACTOR VESSEL
REACTOR DRUM	ENCLOSES THE FUEL CORE AND COMPONENTS
BIOLOGICAL SHIELD	**CONCRETE/LEAD** WHICH ABSORBS ANY LEAKAGE OF RADIATION. PROTECTS OPERATORS FROM RADIOACTIVITY
CONTROL CRUCIBLE	CONTAINS THE METERS THAT SHOW THE OPERATING QUANTITIES IN THE REACTOR
CONTAINMENT VESSEL	PREVENTS SPREAD OF RADIATION IN CASE OF A MAJOR EXPLOSION, MADE OF **CONCRETE.**



NUCLEAR REACTORS

- ARE ASSEMBLIES OF FISSIONABLE AND OTHER MATERIALS SO ARRANGED AND IN SUFFICIENT QUANTITIES SO AS TO BE CAPABLE OF SUPPORTING A CHAIN REACTION.

FISSIONABLE FUEL

NATURAL URANIUM:

1. **URANIUM 235 (U_{235})**

MAN-MADE (ARTIFICIAL) THRU BREEDING:

2. **URANIUM 233 (U_{23})**
3. **PLUTONIUM 239 (Pu_{239})**

FERTILE MATERIAL

- USED FOR BREEDING TO PRODUCE ARTIFICIALLY MADE FISSIONABLE FUEL

$$U_{238} \longrightarrow Pu_{239}$$

$$\text{THORIUM}_{232} \longrightarrow U_{233}$$

NATURAL URANIUM COMPOSITION		
U_{238}	99.3%	FROM PK. NAG 99.282%
U_{235}	0.7%	0.712%
U_{234}	—TRACES—	0.006%

HEAT RELEASE OF U_{235}

FOR EVERY 1 lb (1 kg) OF U_{235} FISSIONED, 0.00091 lb OF ITS MASS IS CONVERTED TO ENERGY

0.00091 lb (kg)

HEAT RELEASE:

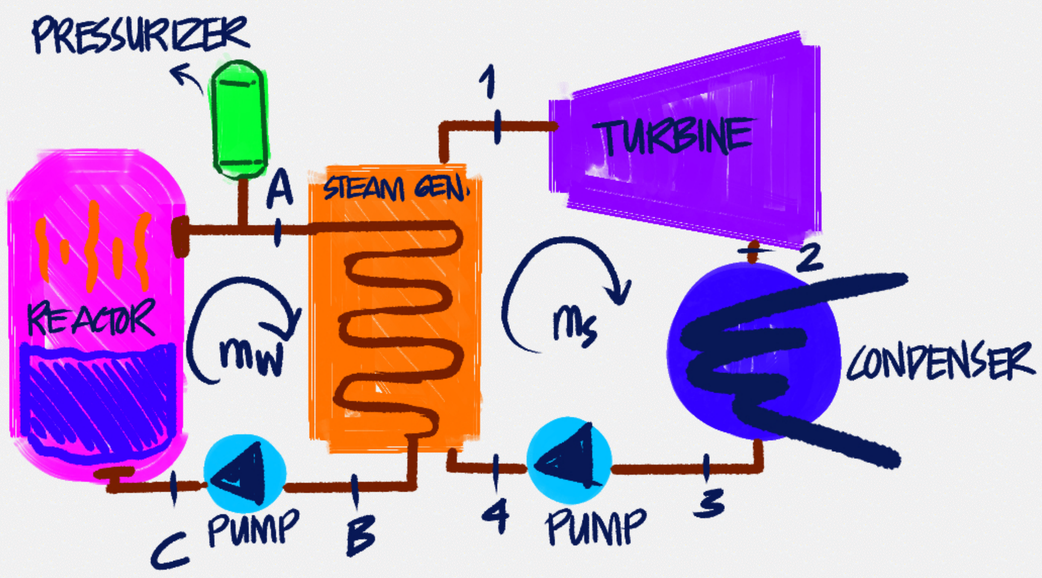
→ 8.19×10^{10} KJ/kg U_{235}

→ 23,000 $\frac{\text{kW-hr}}{\text{g}U_{235}}$

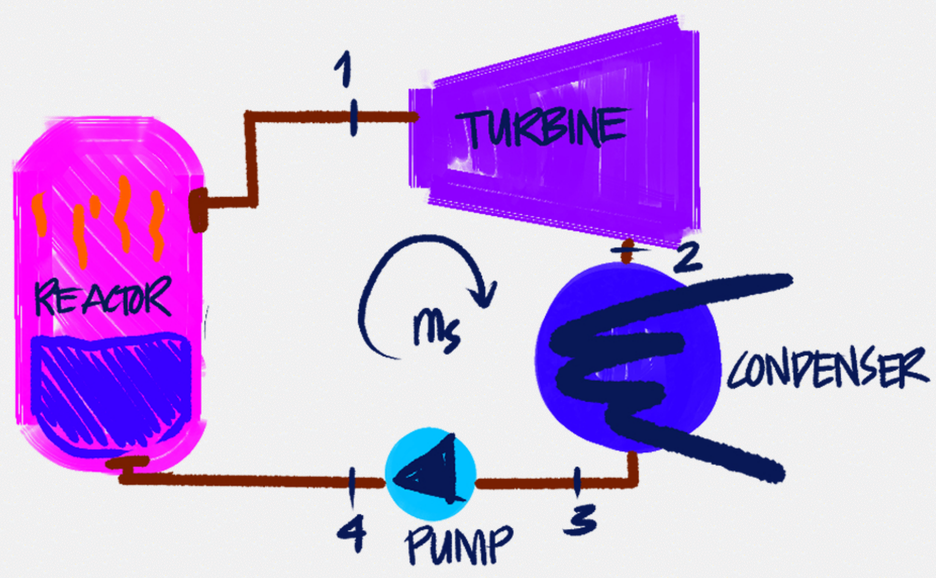
TYPES OF REACTORS

PRESSURIZED WATER REACTOR (PWR)	- USES HIGH PRESSURE **(WITHOUT BOILING)** LIGHT OR HEAVY WATER AS **BOTH MODERATOR AND COOLANT**. IT IS THEN CONNECTED TO A STEAM GENERATOR. - **MORONG, BATAAN - 620 MW**. SUPPLY POWER TO THE LUZON AREA.
BOILING WATER REACTOR (BWR)	- **SIMPLEST** FORM OF NUCLEAR REACTOR BUT MORE **RISK OF CONTAMINATION** - **FEEDWATER GOES DIRECTLY INTO THE REACTOR** (FEEDWATER SERVES AS THE COOLANT) - DILIMAN, QUEZON CITY – FIRST EXPERIMENTAL REACTOR. CAPACITY OF **1 MW**.
HEAVY WATER REACTOR (HWR)	- FIRST ALTERNATIVE TO THE LIGHT-WATER TYPES. **HEAVY WATER OR DEUTERIUM** AS COOLANT. - STILL LIQUID-COOLED AND **CAN EITHER BE PWR OR BWR**.
GAS-COOLED REACTORS (GCR)	- USES **CARBON DIOXIDE AS COOLANT**. HIGH TEMPERATURE IS POSSIBLE AT LOW PRESSURES - HIGH POWER REQUIREMENT FOR PUMPS
FAST REACTORS	- REACTOR CONTAINING **NO MODERATOR**. - **USES FAST OR HIGH-ENERGY NEUTRONS** INSTEAD OF THERMAL NEUTRONS
THERMAL REACTOR	- **USES NEUTRON MODERATOR TO SLOW NEUTRONS**
INTERMEDIATE REACTORS	- EMPLOY NEUTRONS HAVING AN ENERGY **BETWEEN FAST AND THERMAL REACTORS**
HETEROGENEOUS REACTORS	- WHERE FISSIONABLE MATERIAL FOR A REACTOR IS IN THE **FORM OF A LUMP**
HOMOGENEOUS REACTORS	- FUEL (MAY BE IN LIQUID FORM) - **SALT (URANIUM SULFATE)** MIXED WITH **MODERATOR (WATER)**

PRESSURIZED WATER REACTOR (PWR)



BOILING WATER REACTOR (BWR)



NUMBER OF ATOMS/GRAM

6.022×10^{23}

$$\text{No. of atoms/gram} = (1g)\left(\frac{\text{Avogadro's No.}}{\text{Atomic Weight}}\right)$$

$U_{235} \rightarrow 235$

ONE WATT - FISSION

$$1\ \text{Watt} = 3.1 \times 10^{10}\ \frac{\text{atoms}}{s} = 2.68 \times 10^{15}\ \frac{\text{atoms}}{\text{day}}$$

FOR U235

$$q_h = 23{,}000\ \frac{\text{kW-hr}}{g\,U_{235}} \quad \Big| \quad \text{MASS} = 236.98\ \text{amu}$$

MASS PROTONS = 1.00759 amu | 92 – P
NEUTRONS = 1.00898 amu | 143 – N
235

A BARN IS APPROXIMATELY THE CROSS-SECTIONAL AREA OF A URANIUM NUCLEUS.

$$1\ \text{BARN} = 10^{-28}\ m^2$$

EINSTEIN'S THEORY

$$E = mc^2 = hf$$

$c = \lambda f$

$h = 6.625 \times 10^{-34}\ J \cdot s$

$h = 6.625 \times 10^{-27}\ erg \cdot s$

$c = 3.8 \times 10^{8}\ \frac{m}{s}$

$$KE = m_o c^2\left[\frac{1}{\sqrt{1-\frac{v^2}{c^2}}} - 1\right]$$

CONVERSIONS

$1\ J = 10^{7}\ erg$

$10\ Mev = 1.6 \times 10^{-5}\ erg$

$10\ Mev = 1.6 \times 10^{-12}\ J$

Mev → MEGA-ELECTRON VOLTS

h → PLANCK'S CONSTANT

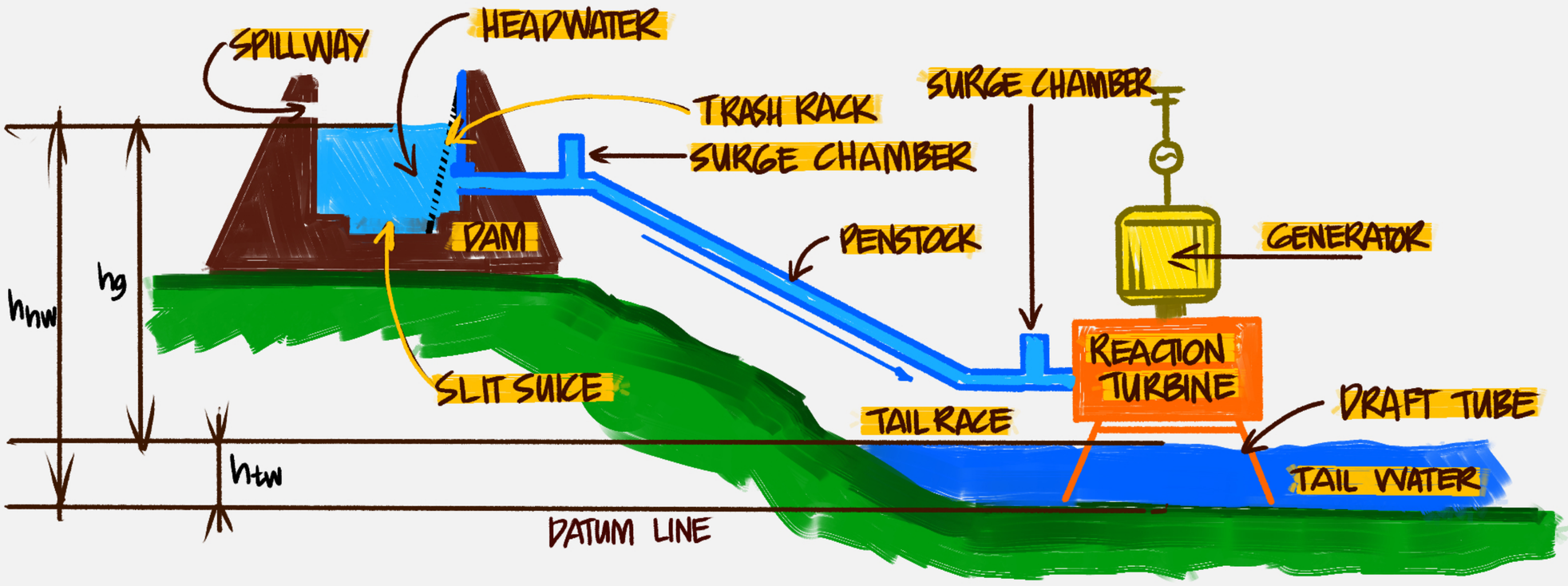
$1\ amu = 1.66 \times 10^{-24}\ g$

$= 931\ \frac{Mev}{amu}$

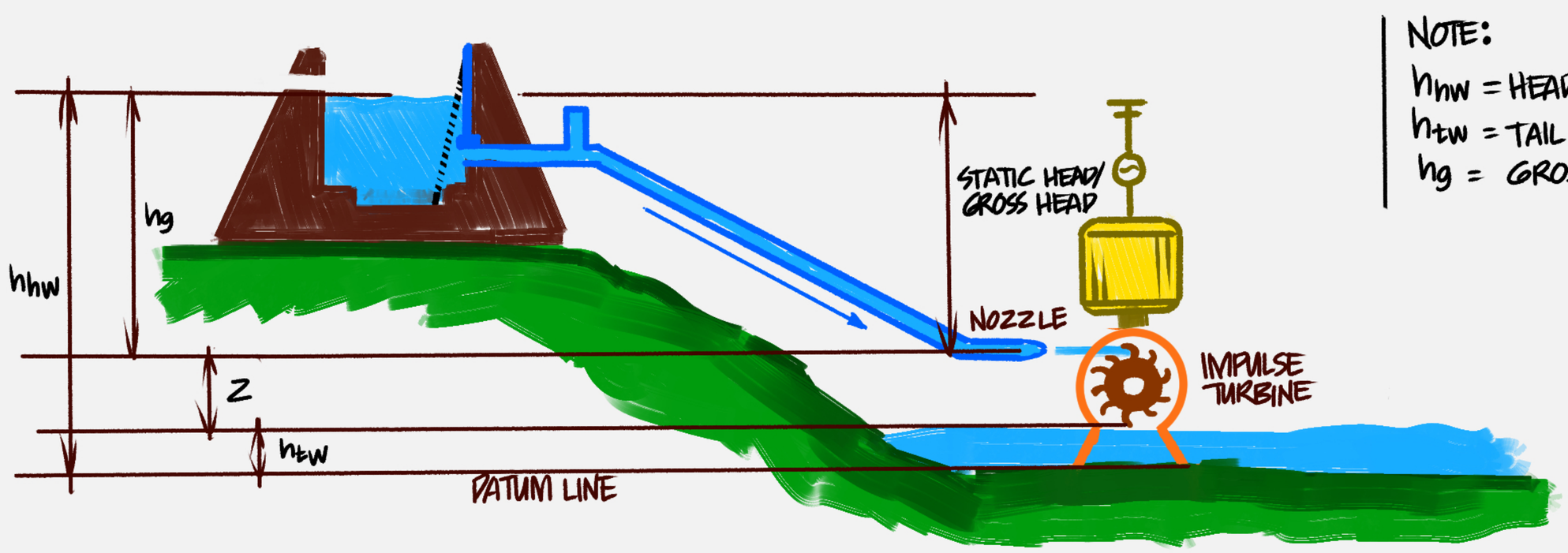
HYDROELECTRIC POWER

- ELECTRIC POWER IS **PRODUCED BY FALLING WATER THAT ROTATES A TURBINE.** THE POTENTIAL ENERGY OF WATER AT HIGH LEVEL IS CONVERTED TO MECHANICAL ENERGY BY THE TURBINE. MOST HYDROELECTRIC POWER PLANTS ARE **USED TO COPE WITH PEAK LOAD.** CAN **BE EASILY STOPPED OR STARTED.**

MEDIUM AND LOW HEAD PLANTS: REACTION TURBINE



HIGH HEAD PLANTS: IMPULSE TURBINE

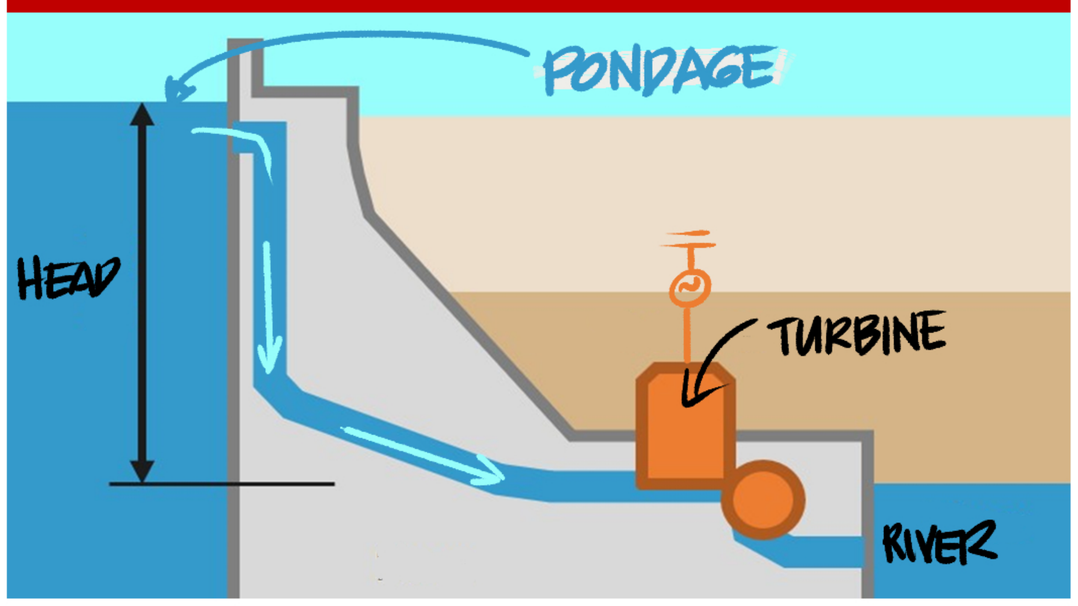


RESERVOIR	**STORES WATER** DURING RAINY THEN SUPPLY DURING SUNNY. STORES WATER FROM THE UPPER RIVER OR WATER FALLS.
SPILLWAY	**A WEIR IN THE RESERVOIR.** DISCHARGES EXCESS WATER TO **MAINTAIN THE HEAD OF THE PLANT.**
DAM	THE **CONCRETE STRUCTURE** THAT **ENCLOSES THE RESERVOIR.** USED FOR WATER STORAGE AND CREATES HEAD
INTAKE STRUCTURE	CONSISTS OF **RACKS OR SCREENS.** PREVENT TRASH/DEBRIS INTO THE TURBINE RUNNERS.
SILT SLUICE	CHAMBER THAT **COLLECTS AND DISCHARGES MUD.**
TRASH RACK	SCREEN THAT **PREVENTS TRASH/CONTAMINANTS** TO ENTER THE PENSTOCK.

WATER WAY	
PENSTOCK	CONDUIT THAT LEADS WATER FROM **RESERVOIR TO TURBINE**
TAILRACE	A CHANNEL WHICH LEADS WATER **FROM TURBINE TO TAILWATER**
SURGE TANK OR CHAMBER	
SURGE TANK	IS USED TO **REDUCE THE WATER HAMMER** DURING DECREASE IN TURBINE LOAD.
SURGE CHAMBER	A STANDPIPE CONNECTED TO THE ATMOSPHERE AND ATTACHED TO THE PENSTOCK SO **THAT THE WATER WILL BE AT ATMOSPHERIC.**
WATER HAMMER	BECAUSE OF **SUDDEN STOPPAGE OF WATER FLOW** IN A PIPE.

DRAFT TUBE	AN INTEGRAL PART OF REACTION TURBINE USED TO RECOVER ENERGY HEAD. IT CONNECTS THE TURBINE OUTLET TO THE TAILWATER SO THAT THE TURBINE CAN BE SET ABOVE THE TAILWATER LEVEL.
TAILWATER	WATER THAT IS DISCHARGED FROM THE TURBINE.
ISOLATED CHAMBER	PROVIDE FOR INSTALLATION OF CONTROL EQUIPMENT OF GATE HOISTS OR VALVES ON PIPES.
WICKET GATES	CONTROL THE POWER AND SPEED OF TURBINE
JET DEFLECTOR	USE TO MINIMIZE THE SPEED RISE DUE TO A SUDDEN LOAD REJECTION
METACENTER	THE POINT WHERE THE BUOYANT FORCE AND THE CENTER LINE INTERSECTS EACH OTHER

RUN-OF-THE-RIVER (LOW HEAD) HYDROPOWER

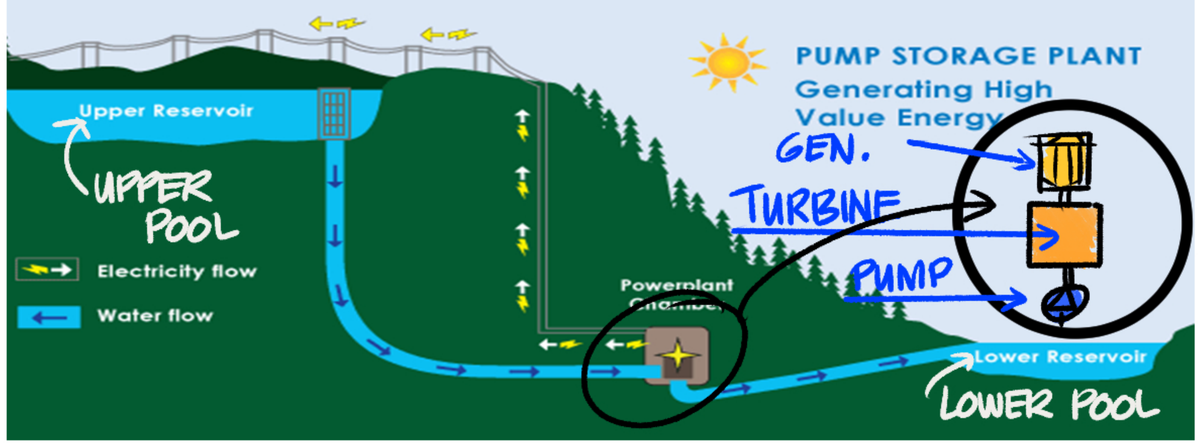


PONDAGE

THE WATER BEHIND THE DAM OF A RUN-OF-THE-RIVER HYDRO-ELECTRIC PLANT.

PUMPED STORAGE HYDROP.P (HYDRAULIC ACCUMULATOR)

INVOLVES THE USE OF OFF-PEAK ENERGY TO STORE WATER AND TO USE THE STORED WATER TO GENERATE EXTRA ENERGY TO COPE WITH THE PEAK LOAD.



TURBINE SELECTION BASED ON HEAD

NET HEAD	TYPE OF TURBINE
UPTO 70 ft	PROPELLER TYPE
70 - 110	PROPELLER / FRANCIS
110 - 800	FRANCIS
800 - 1300	IMPULSE / FRANCIS
1300 & ABOVE	IMPULSE

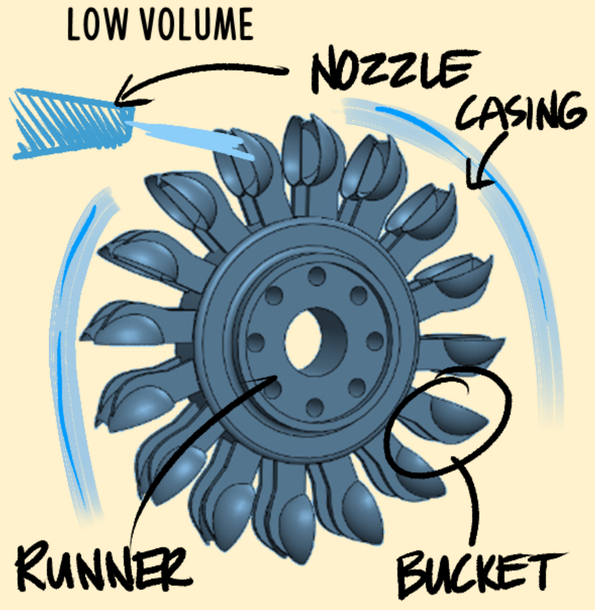
TYPES OF HYDRAULIC TURBINES

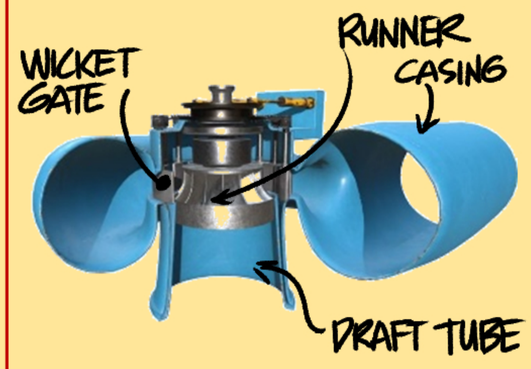
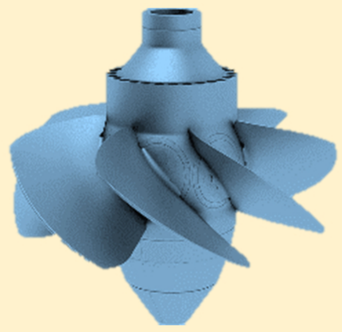
REACTION TURBINE

- POWER FROM THE COMBINED ACTION OF PRESSURE AND VELOCITY OF THE WATER THAT FILLS THE RUNNER AND WATER PASSAGES.
- HAS DRAFT TUBE WHICH KEEPS THE TURBINE UP TO 5 M (15 FT) ABOVE TAILWATER
- HIGHER CONVERSION EFFICIENCY THAN IMPULSE ABOUT 85% - 90%

IMPULSE TURBINE

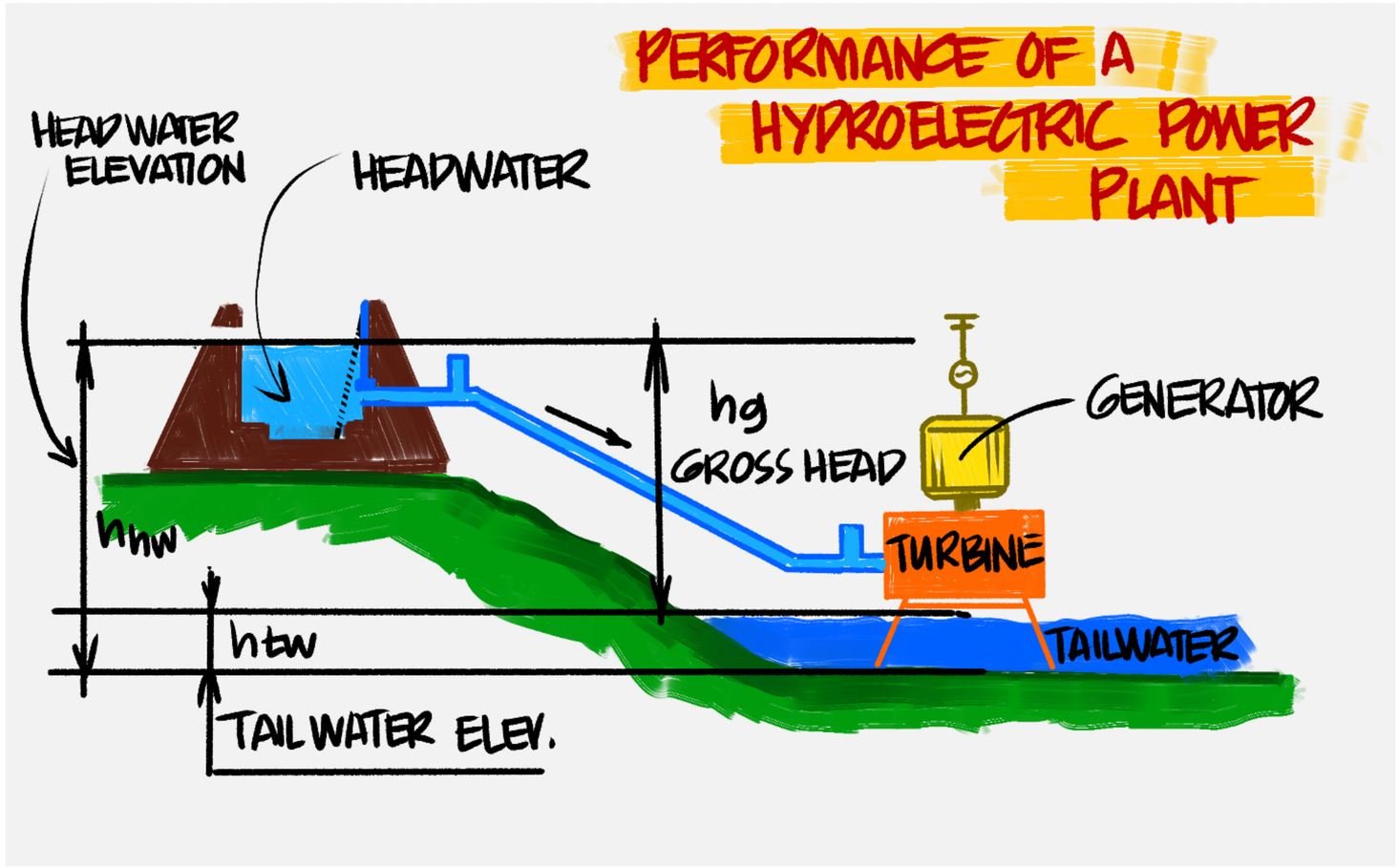
- IT UTILIZES KINETIC ENERGY OF HIGH VELOCITY JET WHICH ACTS UPON A SMALL PART OF THE CIRCUMFERENCE AT AN INSTANT.
- TANGENTIAL WHEEL OR PELTON WHEEL
- HAS NO DRAFT TUBE
- CONVERSION EFFICIENCY: 80% - 90%
- MOVEMENT OF WATER IS TANGENTIAL.
- HIGH HEAD (150 M AND ABOVE), LOW VOLUME



TYPES		
FRANCIS TYPE	- NAMED AFTER JAMES B. FRANCIS - CONVERSION EFFICIENCY 90-94% - MEDIUM HEAD	
PROPELLER & KAPLAN TYPE	- VERY LOW HEAD	
PROPELLER (FIXED BLADE)	- FOR LOW HEAD - REDUCED NUMBER OF BLADES - INWARD FLOW AXIAL - CONVERSION EFFICIENCY: 80%	
KAPLAN (ADJUSTABLE BLADE)	- FOR LOW HEAD, LARGE VOLUME - INWARD FLOW AXIAL - CONVERSION EFFICIENCY: MORE OR LESS 93%	PROPELLER/KAPLAN TYPE

CLASSIFICATION OF HYDRO PP. ACCDG. TO HEAD	
LOW HEAD	6 - 30 (m)
MEDIUM	30 - 150 (m)
HIGH	150 & ABOVE (m)

PERFORMANCE OF A HYDROELECTRIC POWER PLANT



GROSS HEAD

$$h_g = h_{hw} - h_{tw}$$

FRICTION HEAD LOSS

⊙ DARCY'S EQN.	⊙ MORSE'S EQN.
$h_f = f\left(\frac{L}{D}\right)\left(\frac{V^2}{2g}\right)$	$h_f = 2f\left(\frac{L}{D}\right)\left(\frac{V^2}{g}\right)$

NET HEAD

$$h = h_g - h_f$$

PENSTOCK EFFICIENCY

$$\text{PENSTOCK EFF. } (e_p) = \frac{h}{h_g}$$

VOLUME FLOW RATE

$$Q = \text{AREA (VELOCITY)} = A \times V$$

WATER POWER

$$P_W = \gamma Q h$$

TURBINE EFFICIENCY

$$e_t = \frac{P_t \longrightarrow \text{TURBINE POWER}}{P_W \longrightarrow \text{WATER POWER}}$$

ELEC'L / GENERATOR EFFICIENCY

$$e_e = \frac{P_e}{P_t} \quad | \quad P_e = \gamma Q h (e_t e_e)$$

GENERATOR SPEED, N

$$N = \frac{120f}{P} \quad | \quad f = \text{FREQUENCY IN Hz}, \; P = \text{NO. OF POLES}$$

HYDRAULIC EFFICIENCY

$$e_h = \frac{h_u \longrightarrow \text{UTILIZED HEAD}}{h \longrightarrow \text{NET HEAD}}$$

TOTAL EFFICIENCY

$$e_{TOTAL} = e_h e_m e_v \quad | \quad e_h = \text{HYDRAULIC EFF.}, \; e_m = \text{MECHANICAL EFF.}, \; e_v = \text{VOLUMETRIC EFF.}$$

HEADS BY DIFFERENT TYPES OF TURBINE

REACTION (FRANCIS, KAPLAN)	$h = \frac{P}{\gamma} + z + \left(\frac{V_A^2 - V_B^2}{2g}\right)$
IMPULSE (**PELTON**)	$h = \frac{P}{\gamma} + \frac{V^2}{2g}$

PERIPHERAL COEEFICIENT

$$\phi = \frac{V_p}{V_j} = \frac{\pi D N}{\sqrt{2gh}}$$

TURBINE SPEED FACTOR
SPEED RATIO

$V_p = \pi D N$ = PERIPHERAL VELOCITY
$V_j = \sqrt{2gh}$ = JET VELOCITY

SPECIFIC SPEED OF HYDRAULIC TURBINE

↳ PREDICT PERFORMANCE OF HYDRAULIC TURBINES

⊙ ENGLISH UNITS

$$N_S = \frac{N\sqrt{HP}}{h^{5/4}}$$

h = NET HEAD, ft

⊙ SI UNITS

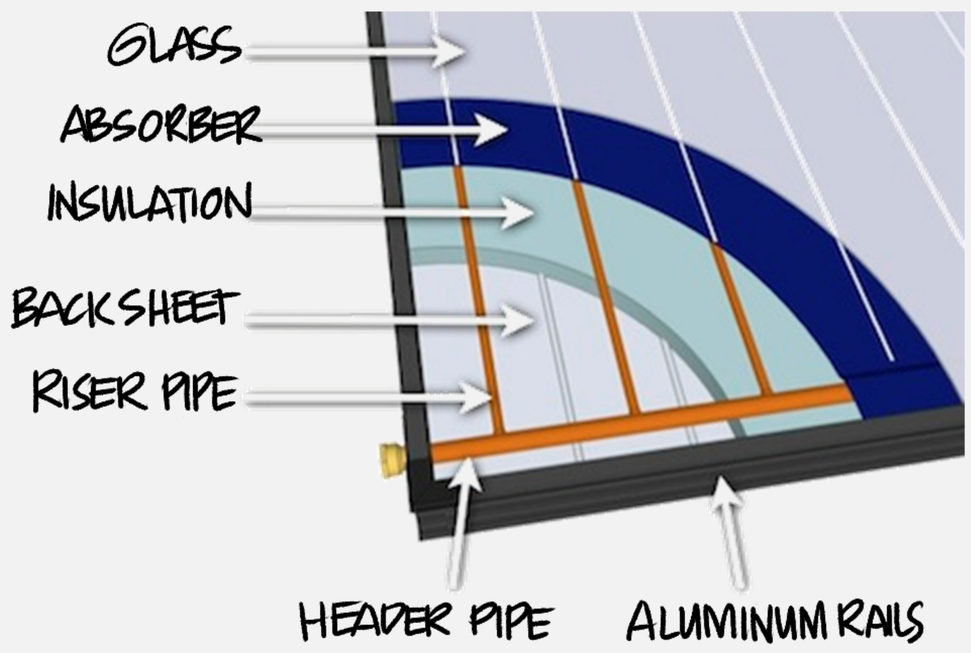
$$N_S = \frac{0.2623\,N\sqrt{kW}}{h^{5/4}}$$

h = IN METERS

NON-CONVENTIONAL SOURCES

- ALSO REFERRED TO AS **RENEWABLE ENERGY SOURCES**, THESE ARE ACTUALLY **ENERGY FLOWS WHICH ARE REPLENISHED AS THEY ARE USED.**

SOLAR ENERGY



- ENERGY PRODUCED FROM HEAT AND LIGHT WHICH IS RADIATED FROM THE SUN

PYRANOMETER	IS THE INSTRUMENT USED TO MEASURE THE TOTAL SOLAR RADIATION
PHOTOVOLTAIC CELL	IS A DEVICE WHICH CONVERTS SOLAR ENERGY TO ELECTRICAL ENERGY.
SOLAR COLLECTORS	WHOSE IDEAL CHARACTERISTICS ARE HIGH ABSORPTIVITY AND LOW EMISSIVITY

FORMS OF SOLAR RADIATION

A. BEAM OR DIRECT RADIATION – WITHOUT HAVING BEAM SCATTERED BY THE ATMOSPHERE.
B. DIFFUSE RADIATION – DIRECTION IS CHANGED BY SCATTERING.
C. TOTAL OR GLOBAL SOLAR RADIATION – THE SUM OF BEAM AND DIFFUSE RADIATION.

SOLAR ENERGY RECEIVED

$$E_S = Q_S\,[A(1-i)]$$
$$Q_{SUN} = Q_W + PE + Q_{LOSS}$$

Q_S = SOLAR ENERGY W/O ATM. INTERFERENCE
A = SURFACE AREA OF COLLECTOR
i = ATMOSPHERIC INTERFERENCE

SOLAR CONSTANT

SOLAR CONSTANT = 1353 W/m^2

CLASSIFICATIONS:

1. NATURAL CIRCULATION SYSTEM

- TANK IS ABOVE COLLECTOR, **NO CIRCULATION AT NIGHT**, AUXILIARY EQUIPMENT NEEDED.

2. FORCED CIRCULATION SYSTEM

- **REQUIRES A PUMP TO CIRCULATE WATER**, TANK MAY NOT BE LOCATED ABOVE COLLECTOR. **EMPLOYS CHECK VALVE** TO PREVENT REVERSE CIRCULATION OF WATER AND TO **PREVENT NIGHTTIME THERMAL LOSSES FROM THE COLLECTOR.**

SOLAR COLLECTORS

- WHOSE IDEAL CHARACTERISTICS ARE HIGH ABSORPTIVITY AND LOW EMISSIVITY.

- **FLAT PLATE COLLECTORS (FPC)**
  - MEASURE OF PERFORMANCE IS BY MEANS OF **COLLECTION EFFICIENCY.**
  - AREA ABSORBING RADIATION IS THE SAME AS THE AREA INTERCEPTING RADIATION. USES BOTH BEAM AND DIFFUSE RADIATION

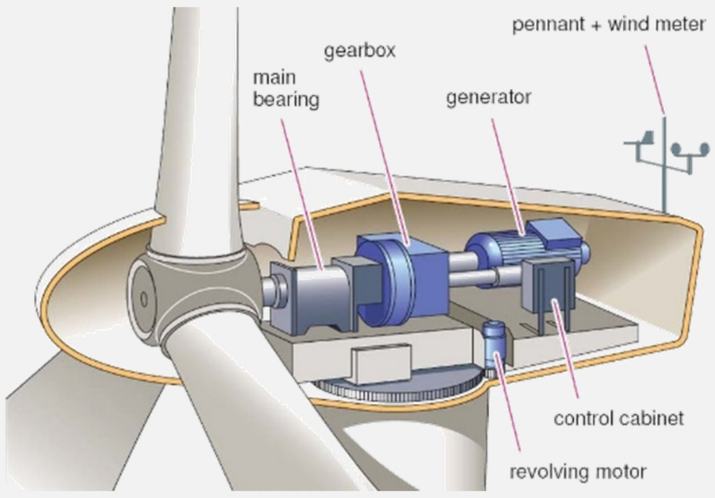
COLLECTION EFFICIENCY

$$\text{COLLECTION EFFICIENCY} = \frac{\text{USEFUL GAIN}}{\text{INCIDENT SOLAR RADIATION}}$$

$$\text{CONCENTRATION RATIO} = \frac{\text{APERTURE A.}}{\text{RECEIVER A.}}$$

- **FOCUSING OR CONCENTRATING COLLECTORS**
  - UTILIZE OPTICAL SYSTEMS, EITHER REFLECTORS OR REFRACTORS.
  - USES BEAM RADIATION ONLY.

WIND POWER PLANT



WINDS

- ARE A RESULT OF AIR **MOTION CAUSED BY UNEVEN HEATING OF THE EARTH'S SURFACE** BY THE SUN AND ROTATION OF THE EARTH.

WINDMILLS

- ANY VARIOUS MECHANISMS, SUCH AS, **MILLS, PUMP, ELECTRIC GENERATORS, OPERATED BY THE FORCE OF WIND** AGAINST VANES OR SAILS RADIATING ABOUT A HORIZONTAL SHAFT.

TYPE OF WINDMILLS

TURBINE | ROTOR | PROPELLER | DUTCH SAIL | PANEMONE

BETZ'S LAW

- THE **MAXIMUM POSSIBLE ENERGY TO BE DERIVED FROM A WIND TURBINE.** THE IDEAL OR MAXIMUM THEORETICAL EFFICIENCY, **ALSO CALLED POWER COEFFICIENT**, OF A WIND TURBINE IS THE **RATIO OF MAXIMUM POWER FROM THE WIND TO THE TOTAL POWER AVAILABLE IN THE WIND.**
- THE FACTOR **0.593** IS KNOWN AS **BETZ'S COEFFICIENT**. IT IS THE **MAXIMUM FRACTION OF THE POWER** IN A WIND STREAM THAT CAN BE EXTRACTED. 0.593

PERFORMANCE OF A WIND POWER PLANT

PUMP POWER

$$W_p = \frac{\gamma Q h}{e_p}$$

$\gamma Q h$ → OUTPUT

e_p → PUMP EFFICIENCY

KINETIC ENERGY

$$KE_{AIR} = \frac{1}{2} m V^2$$

m = MASS FLOW RATE AIR
V = AVE. VELOCITY AIR

VOLUME OF AIR

$$V = \frac{mRT}{P} \quad | \quad V = \frac{\pi}{4} D^2 \times \text{VELOCITY}$$

AERODYNAMIC EFFICIENCY

$$e_A = \frac{\text{PUMP POWER}}{\text{KINETIC ENERGY of AIR}}$$

MAX. CONVERSION EFFICIENCY → CHOOSE HIGHER VALUE!

BIO-ENERGY OR BIO-MASS

- BIOMASS UNDERGO DECOMPOSITION IN THE ABSENCE OF OXYGEN IN A BIOGAS PLANT AND FORM A MIXTURE OF GASES. THIS MIXTURE IS THE BIOGAS.
- ITS MAIN **CONSTITUENT IS METHANE.**

PYROLYSIS

- AN IRREVERSIBLE CHEMICAL CHANGE CAUSED BY **THE ACTION OF HEAT IN THE ABSENCE OF OXYGEN.**

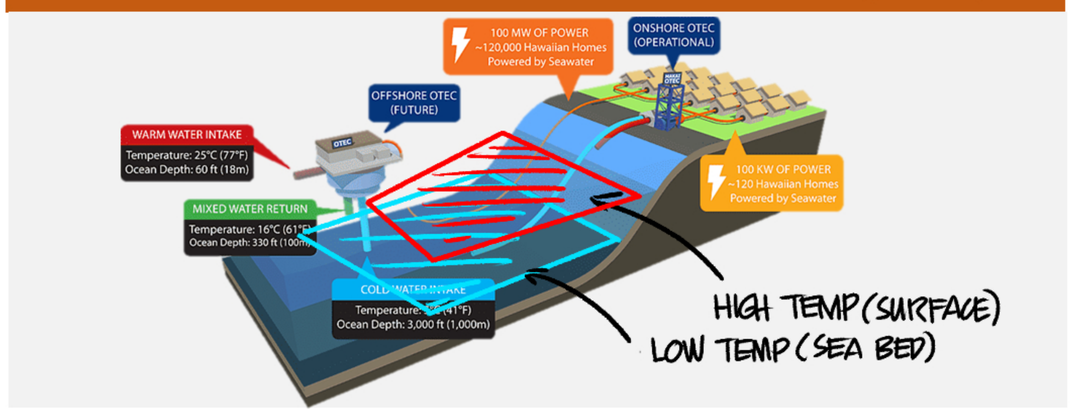
COMBUSTION/GASIFICIATION

- **COMPLETE COMBUSTION** TAKES PLACE **WITH EXCESS OXYGEN OR AT LEAST 100% THEORETICAL OXYGEN**, WHILE GASIFICATION TAKES PACE WITH AN OXYGEN DEFICIT.

TIDAL POWER

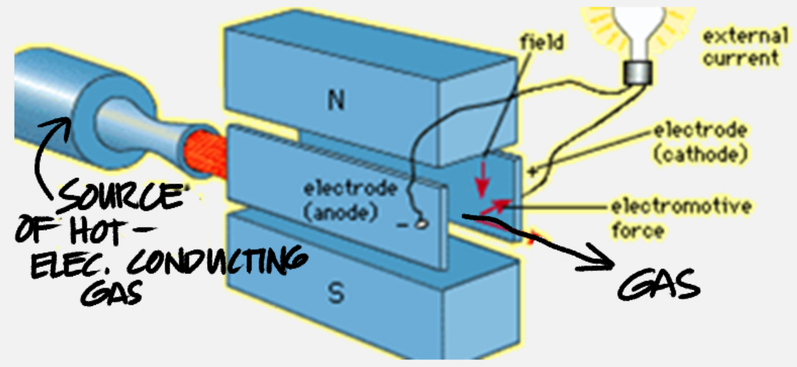
- HYDRO-ELECTRIC POWER UTILIZING **THE DIFFERENCE IN ELEVATION BETWEEN HIGH AND LOW TIDE** TO PRODUCE ENERGY
- IN THE PHILIPPINES, **COMMERCIALIZATION IS NOT FULL-SCALE** SINCE IT IS FOUND THAT THE **AVERAGE DIFFERENCE IS ONLY ABOUT 6 METERS.**

OCEAN THERMAL ENERGY CONVERSION (OTEC)



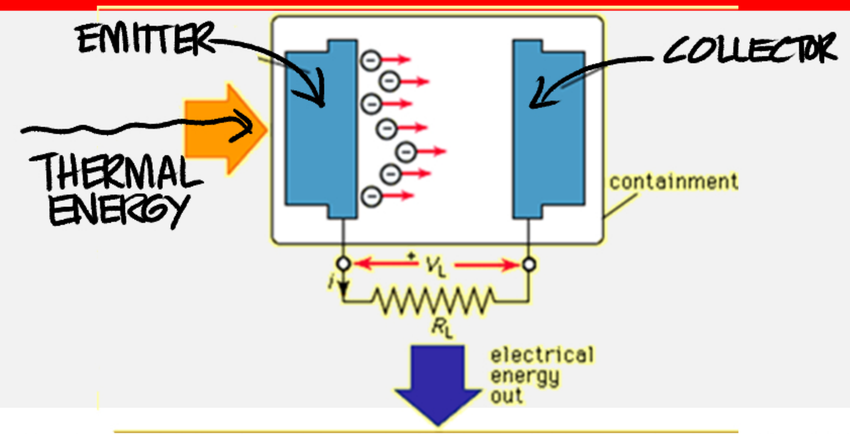
- KNOWN AS **LOW THERMAL HEAD PLANT**, IT **UTILIZES THE TEMPERATURE DIFFERENCE BETWEEN THE OCEAN SURFACE WATER AND THE WATER AT THE SEA BOTTOM.**

MAGNETO HYDRODYNAMIC PLANT



- COMBUSTION GASES PRODUCED IN A COMBUSTION CHAMBER AT HIGH PRESSURE AND TEMPERATURE AND **SCATTERED WITH METAL VAPOR TO INCREASE ITS ELECTRICAL CONDUCTIVITY**
- PASSES THROUGH EXPANSION TUBE LINED WITH STRONG MAGNETIC FIELD. THIS **INDUCES AN ELECTRIC VOLTAGE IN THE GAS CONDUCTOR.**

THERMIONIC CONVERTER



- IS A DEVICE WHICH **CONVERTS HEAT ENERGY DIRECTLY TO ELECTRICAL ENERGY.** ALL **METALS AND SOME OXIDES** HAVE FREE ELECTRONS WHICH ARE RELEASED ON HEATING.

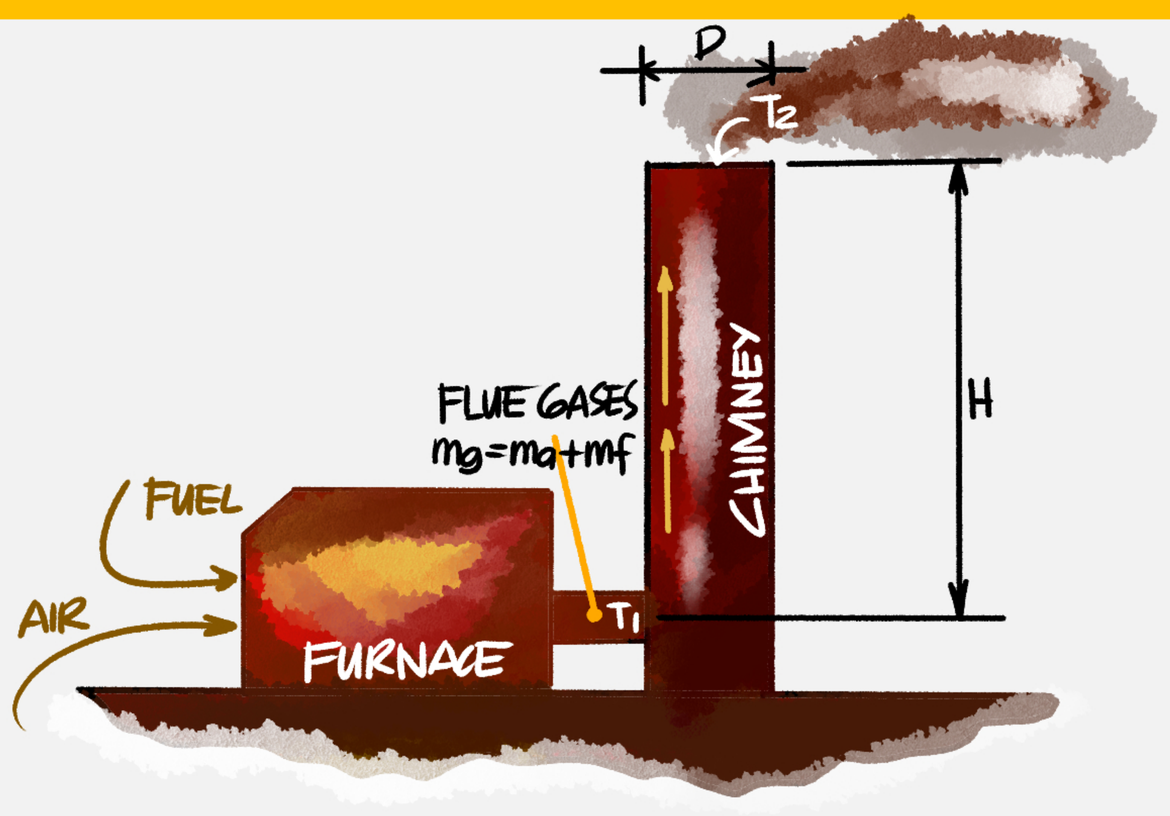
FUEL CELL

- IS A DEVICE **WHICH CONVERTS CHEMICAL ENERGY TO ELECTRICAL ENERGY.** FUEL CELLS PRODUCE ELECTRICITY FROM AN **ELECTROCHEMICAL REACTION BETWEEN HYDROGEN AND OXYGEN.**

CHIMNEYS

- DISPOSE THE EXHAUST GASES AT A CONSIDERABLE HEIGHT AND PRODUCE THE NECESSARY DRAFT FOR THE FLOW OF THE GASES.
- CHIMNEYS FOR BRICK OR CONCRETE CONSTRUCTION
- **STACKS** FOR STEEL CONSTRUCTION.

CHIMNEYS



DRAFT PRESSURE, hw

$$h_w = (\rho_a - \rho_g)\, H$$ | H → HEIGHT OF CHIMNEY

DENSITY OF AIR

$$\rho_a = \frac{P}{m_a R_a}$$

DENSITY OF FLUE GAS

$$\rho_g = \frac{P}{m_g T_g}$$ | NOTE: $m_g = m_a + m_f$ | $R_g = \frac{8.3143}{\text{MOLECULAR WT. OF GAS}}$

AVERAGE TEMPERATURE OF FLUE GASES

$$T_g = \frac{T_1 + T_2}{2}$$

VOLUME FLOW OF FLUE GASES

$$Q = \text{AREA} \times \text{VELOCITY}$$
$$= \frac{\pi}{4} D^2 \times \text{VELOCITY}$$
$$= \frac{m_g R_g T_g}{P}$$

THEORETICAL VELOCITY OF FLUE GAS, V

$$V = \sqrt{2g \times \frac{h_w}{\rho_g}}$$

- ACTUAL VELOCITY OF FLUE GASES IN CHIMNEY IS ONLY **30% TO 50%** OF THEORETICAL VELOCITY
- MULTIPLY THE THEORETICAL VELOCITY BY A VELOCITY COEFFICIENT OF **0.30** TO **0.50**. USUAL ASSUMPTION IS **0.40** FOR *CV*.

$$\text{ACTUAL VEL.} = (C_V)(\text{THEO. VEL.})$$

CHIMNEY DIAMETER

$$Q_g = \frac{\pi}{4} D^2 V_a$$
$$D = \sqrt{\frac{4Q_g}{\pi V_a}}$$

FOR TAPERED CHIMNEY; USE SMALLEST Ø

MACHINE FOUNDATION

- **FOUNDATION**
  - PART OR STRUCTURE WHICH **TRANSMIT THE LOADS TO THE SUPPORTING MATERIAL.**
- **MONOLITHIC FOUNDATION**
  - IS A **CONCRETE FOUNDATION** WHICH IS FORMED BY **POURING THE ENTIRE CONCRETE MIXTURE CONTINUOUSLY** AT ONE TIME AND ALLOWING THE **STRUCTURE TO HARDEN AS A WHOLE UNIT.**
- **GROUTING**
  - A PROCESS OF **FILLING A SMALL CLEARANCE BETWEEN MACHINE AND FOUNDATION,** AFTER THE MACHINE IS ALIGNED AND LEVELED, BY **USING A SPECIAL HARDENING MIXTURE.**

MATERIALS

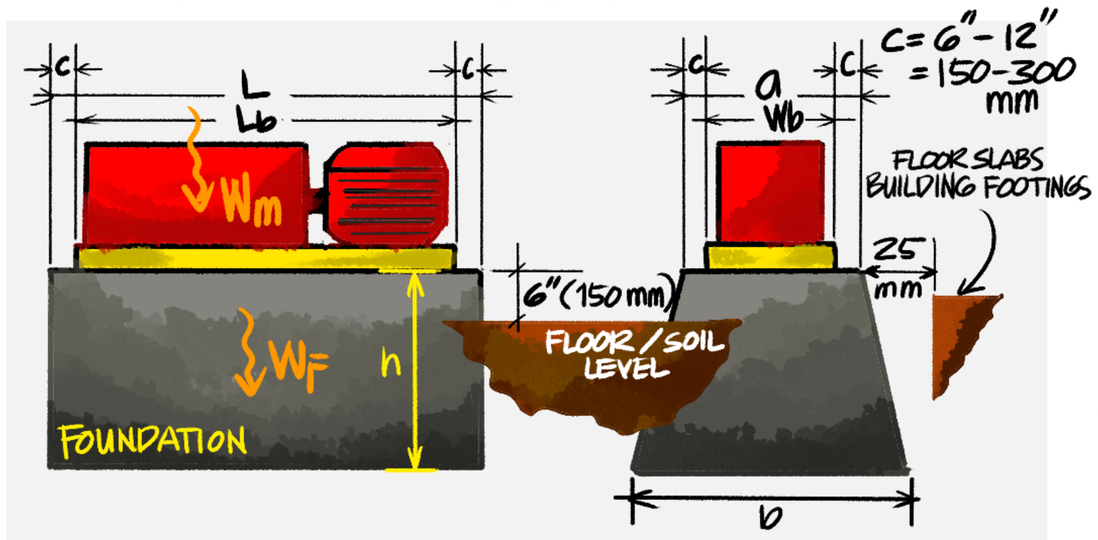
- THE FOUNDATION SHOULD BE **CONCRETE** $\rho = 2.66$ tons/m³
- ENGINE SHOULD NOT BE PLACED ON THE FOUNDATION UNTIL **10** DAYS, NOR OPERATED UNTIL AFTER ANOTHER **10** DAYS.

FOUNDATION = CONCRETE (1:2:4)
(1 PART CEMENT : 2 PARTS SAND : 4 PARTS GRAVEL & STONE)
↳ 50 mm MAX

CONCRETE	CEMENT	SAND	STONE
1 yard³	6 SACKS	0.44 yd³	0.88 yd³
1 m³	7.8 SACKS	0.44 m³	0.88 m³

RECOMMENDED DIMENSIONS

NOTE: 1 yd = 3 ft



DEPTH OF FOUNDATION

$$h = (3.2 - 4.2)\,\text{ENGINE STROKE}$$

LENGTH OF FOUNDATION

$$L = Lb + 2C$$

UPPER WIDTH OF THE FOUNDATION

$$a = Wb + 2C$$

WEIGHT OF FOUNDATION

$$Wf = (3 \text{ to } 5)(Wm)$$ ↳ WEIGHT OF MACHINE

or

$$Wf = e(We)\sqrt{N}$$

e = EMPHERICAL COEFF.
We = WEIGHT OF ENGINE, kgs.
N = ENGINE SPEED, rpm

THE LOWER FACTOR FOR WELL-BALANCED MULTI-CYLINDER ENGINES. HIGHER FACTOR GOT ENGINES WITH FEWER CYLINDERS, OR ON LESS FIRM SOIL.

TYPE OF ENGINE	CYLINDER ARRANGEMENT	NO. OF CYLINDERS	e
SINGLE ACTING	VERTICAL	1	0.15
		2	0.14
		3	0.12
		4, 6, 8	0.11
	HORIZONTAL	1	0.25
	HORIZONTAL DUPLEX	2	0.24
	HORIZONTAL TWIN DUPLEX	4	0.23
DOUBLE ACTING	HORIZONTAL	1, 2	0.32
	HORIZONTAL WITH TANDEM	4	0.20

PSME: VOLUME OF CONCRETE FOUNDATION; m³/kg

NO. OF CYLINDERS	1	2	3	4	5-8
HIGH SPEED ENGINE	0.152	0.095	0.076	0.065	0.057
MEDIUM SPEED ENGINE	0.190	0.118	0.095	0.080	0.072
LOW SPEED ENGINE	0.228	0.152	0.114	0.099	0.087

MORSE: WEIGHT OF FOUNDATION (kg) PER BRAKE HP

PRIME MOVER	SINGLE CYL.	MULTI-CYLINDER
GAS ENGINE	1135 kg	730 kg
DIESEL ENGINE	910 kg	570 kg
STEAM TURBINE	320 kg	230 kg

BASE WIDTH OF THE FOUNDATION

FACTOR OF SAFETY = 5

$$\frac{Sb}{2} = \frac{Wm + WF}{bL} \quad | \quad b = \text{BASE WIDTH}$$

PSME CODE – DENSITY OF CONCRETE

$$\rho_{CONCRETE} = 2406 \frac{kg}{m^3} \quad | \quad V_F = \frac{W_F}{2406}, \; m^3$$

WEIGHT OF STEEL BAR REINFORCEMENTS

$$W_{SB} = (0.5\% - 1\%)W_F$$

FOUNDATION BOLTS

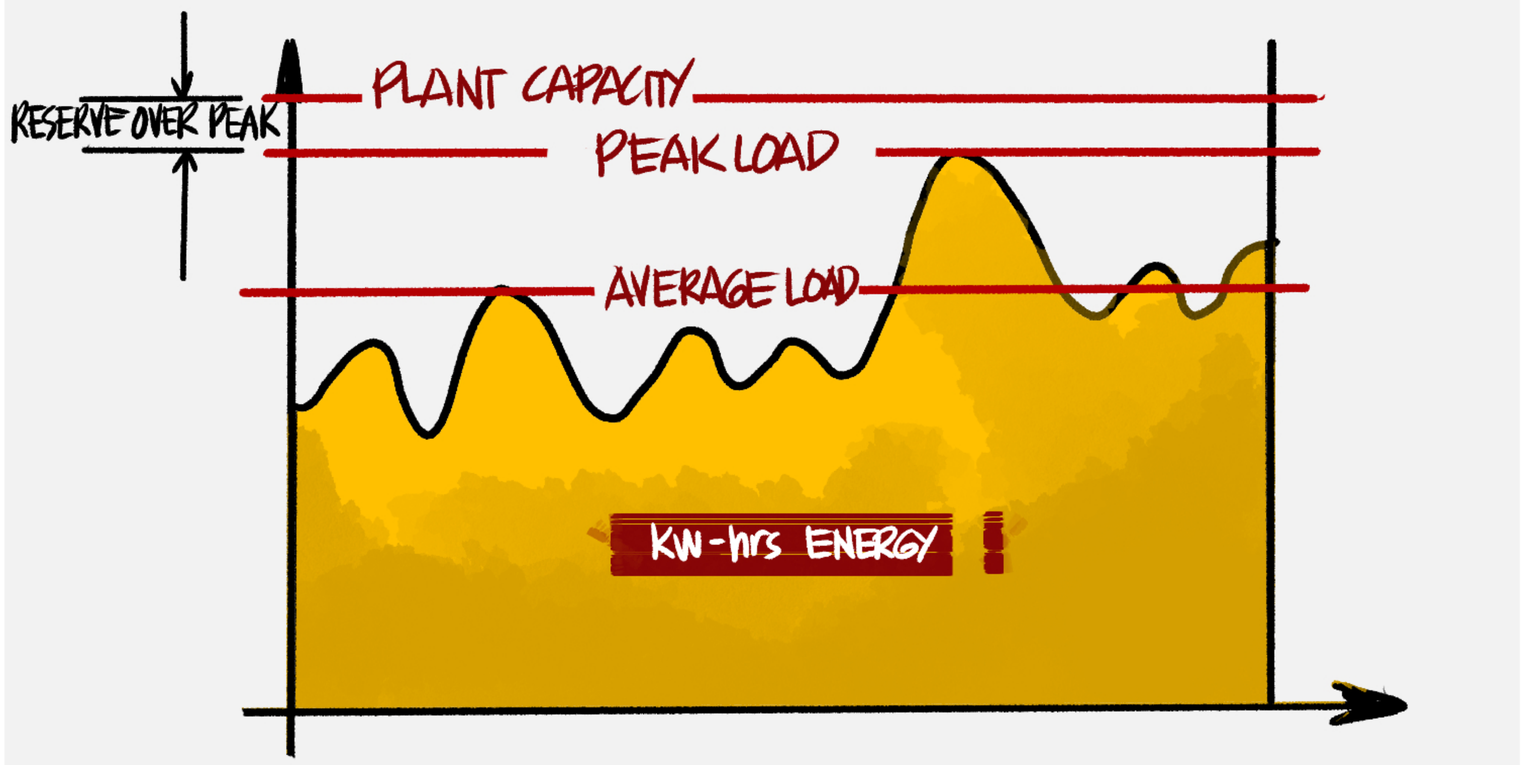
FOUNDATION BOLTS ⟶ SURROUNDED BY PIPE SLEEVE
↳ ø = 3 x ø ANCHOR BOLTS
L = 18 x ø ANCHOR BOLTS

→ NOT BE LESS THAN 12 mm ø
→ IMBEDDED AT LEAST 30 x BOLT ø

- THE UPPER ENDS ARE SURROUNDED BY A **50 MM OR 75 MM SHEET METAL PIPE, 460 MM TO 610 MM LONG** TO PERMIT THEM TO BEND SLIGHTLY TO FIT THE HOLES TO THE BEDPLATE.

VARIABLE LOADS

LOAD CURVE



LOAD CURVE —CURVE OF **POWER VERSUS TIME**, SHOWING **THE VALUE OF A SPECIFIC LOAD FOR EACH UNIT OF THE PERIOD COVERED**. THE ABSCISSA IS USUALLY TIME IN HOURS, DAYS, WEEKS, MONTHS, OR YEARS, AND THE ORDINATE IS KILOWATTS GENERATED.

LOAD DURATION CURVE — IS A CURVE **SHOWING THE TOTAL TIME, WITHIN A SPECIFIED PERIOD**, DURING WHICH THE LOAD EQUALED OR EXCEEDED THE POWER VALUES SHOWN. KILOWATTS ARE USED AS THE ORDINATE, AND NORMALLY, THE **8760** HR OF THE YEAR IS THE ABSCISSA.

RESERVE OVER PEAK

$$\text{RESERVE OVER PEAK} = \text{PLANT CAPACITY} - \text{AVERAGE LOAD}$$

PLANT FACTOR

$$\text{PLANT FACTOR} = \frac{\text{AVERAGE LOAD}}{\text{EQUIPMENT RATING SUPPLYING THE LOAD}}$$

AVERAGE LOAD

$$\text{AVERAGE LOAD} = \frac{\text{kW-hrs ENERGY}}{\text{NO. OF HOURS}}$$

UTILIZATION FACTOR

$$\text{UTILIZATION FACTOR} = \frac{\text{MAX. DEMAND OF SYSTEM}}{\text{RATED CAPACITY OF SYSTEM}}$$

LOAD FACTOR

$$\text{LF} = \frac{\text{AVERAGE LOAD}}{\text{PEAK LOAD}}$$

OPERATION FACTOR

$$\text{OPERATION FACTOR} = \frac{\text{ACTUAL SERVICE (hrs.)}}{\text{TOTAL DURATION PERIOD (hrs)}}$$

CAPACITY FACTOR

$$\text{CAPACITY FACTOR} = \frac{\text{ACTUAL ENERGY PRODUCED}}{\text{MAX. ENERGY PRODUCED ON THE SAME PERIOD}}$$

$$\text{ANNUAL C.F} = \frac{\text{ANNUAL ENERGY PROD. (kW-hrs)}}{\text{kW PLANT CAP.} \times 8760 \text{ hrs.}}$$

USE FACTOR

$$\text{ANNUAL C.F} = \frac{\text{ANNUAL ENERGY PROD. (kW-hrs)}}{\text{kW PLANT CAP.} \times \text{TIME (hrs.)}}$$

DEMAND FACTOR

$$\text{DEMAND FACTOR} = \frac{\text{ACTUAL MAXIMUM DEMAND}}{\text{CONNECTED LOAD}}$$

DIVERSITY FACTOR

$$\text{DIVERSITY FACTOR} = \frac{\Sigma \text{ INDIVIDUAL MAX. DEMAND}}{\text{MAX. SIMULTANEOUS DEMAND}}$$

DUMP POWER	HYDRO POWER IN EXCESS, MADE AVAILABLE BY SURPLUS WATER.
FIRM POWER	ALWAYS AVAILABLE EVEN UNDER EMERGENCY
PRIME POWER	MAXIMUM POTENTIAL POWER CONSTANTLY AVAILABLE FOR TRANSFORMATION INTO ELECTRIC POWER.
COLD RESERVE	AVAILABLE FOR SERVICE BUT NOT IN OPERATION.
HOT RESERVE	IN OPERATION BUT NOT IN SERVICE.
SPINNING RESERVE	RESERVE GENERATING CAPACITY CONNECTED TO THE BUS AND READY TO TAKE LOAD.
RESERVE EQUIPMENT	INSTALLED EQUIPMENT IN EXCESS OF THAT REQUIRED TO CARRY PEAK LOAD. RESERVE EQUIPMENT NOT IN OPERATION IS SOMETIMES REFERRED TO AS STANDBY EQUIPMENT.

BASE-LOAD POWER PLANTS	PEAK-LOAD POWER PLANTS
• STEAM • HYDROELECTRIC • GEOTHERMAL	• DIESEL • GAS TURBINE

ADDITIONAL NOTES:

"APPROXIMATE" FORMULAS (EMPIRICAL) ↳ W/O STEAM TABLE!!

RELATIONSHIP OF T_{SAT} AND P_{SAT}

$$T_{SAT} = \frac{237.7 \ln(1.638 P_{sat})}{17.27 - \ln(1.638 P_{SAT})}$$

$T_{SAT} = {}^{\circ}C$

$P_{SAT} = kPa$

SUPERHEATED STEAM

$$h_s = 2454 + 2.1 T_{{}^{\circ}C} - 50 P_{MPa} + 0.074 (T_{{}^{\circ}C})(P_{MPa})$$

$h_s = \frac{kJ}{kg}$ $\quad T = {}^{\circ}C$ $\quad P = MPa$

- $T < 300^{\circ}F\ [148.89^{\circ}C]$

$$h_g = 2501 + 1.84 T_{{}^{\circ}C} \ ; \frac{kJ}{kg} \qquad h_g = 1061 + 0.45 T_{{}^{\circ}F} \ ; \frac{BTU}{lb}$$

$$h_f = 4.187 T_{{}^{\circ}C} \ ; \frac{kJ}{kg} \qquad h_f = T_{{}^{\circ}F} - 32 \ ; \frac{BTU}{lb}$$

- $T > 300\ ^{\circ}F$

$$h_g = 906.8 + 1.33 T_{{}^{\circ}F} - (1.48 \times 10^{-3})(T_{{}^{\circ}F})^2 \ ; \frac{BTU}{lb}$$

$$h_f = -29.33 + 0.97 T_{{}^{\circ}F} + (9.527 \times 10^{-5})(T_{{}^{\circ}F})^2 \ ; \frac{BTU}{lb}$$

NOTE!!! ↳ $1 \frac{BTU}{lb} = 2.326 \frac{kJ}{kg}$

ADDITIONAL NOTES:

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